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Rio Blanco Oil Shale Project

DETAILED DEVELOPMENT PLAN
TRACT C-a

VOLUME 2

BASELINE CONDITIONS
(Book 1 of 2)

Gulf Oil Corporation . Standard Oil Company(Indiana)

March, 1976

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RIO BLANCO OIL SHALE PROJECT

DETAILED DEVELOPMENT PLAN

TRACT C-a

VOLUME 2

SECTION 3 BASELINE CONDITIONS

(Book 1 of 2)

(Chapters 1 thru 6)

**Submitted To Area Oil Shale Supervisor,
Geological Survey, U.S. Department of
the Interior, Pursuant To Lease No. C-20046**

Gulf Oil Corporation - Standard Oil Company (Indiana)

March, 1976

DDP ABSTRACT

In 1969, the U.S. Department of the Interior initiated planning for a prototype oil shale leasing program that eventually resulted in Gulf Oil Corporation and Standard Oil Company (Indiana) acquiring an oil shale lease for Tract C-a in the Piceance Creek basin of northwest Colorado. Gulf and Standard submitted the high bonus bid for Tract C-a ($210,305,600) at a lease sale in Denver on January 8, 1974. Rio Blanco Oil Shale Project (RBOSP) an organization directed and staffed by representatives of Gulf and Standard, was formed later that year for the purpose of developing Tract C-a.

In the past two years, RBOSP has conducted extensive geotechnical and environmental data collection programs designed to establish baseline conditions on and around Tract C-a and to provide input to engineering studies leading to the selection of mining and processing plans for Tract C-a development. This 4-volume detailed development plan (DDP) describes the baseline conditions and RBOSP's proposed construction and operation of a commercial-scale oil shale complex and support facilities on and around Tract C-a. Three major requirements must be met before development operations on Tract C-a can begin:

- The Area Oil Shale Supervisor, U.S. Geological Survey, must approve the development plan.
- Key Federal and State actions must be fulfilled and permits issued.
- The proposed development described in this plan must be commercially feasible at the time investments are committed.

PROJECT DESCRIPTION

RBOSP's ultimate goal with respect to Tract C-a development is to engage in commercial production of shale oil and associated by-products at as high a production rate as is feasible, consistent with environmental, technical and economic constraints that now prevail or may exist in the future.

Development will consist of open pit mining, off-tract surface retorting, and off-tract disposal of processed shale and overburden, and will be undertaken in two operating phases, each preceded by three-year construction periods. Phase I operation will consist of two stages, wherein first one, then two retort modules will be operated. This modular approach will provide RBOSP the opportunity to gain operating experience, improve process efficiency and confirm capital and operating costs before a full-scale oil shale complex is built. Phase II will be the commercial-scale complex. Table 1 is a summary of information pertinent to RBOSP's proposed development of Tract C-a. Figure 1 depicts the location of proposed RBOSP facilities.

Phase I - Stage 1 operations will begin during 1979 with a small open pit mine and a single TOSCO II retort capable of processing 10,700 tons of oil shale per day to produce approximately 4,500 barrels of pipelineable shale oil daily. Phase I - Stage 1 will include a thermal cracking plant for lowering the viscosity and pourpoint of raw shale oil so that it can be transported by pipeline. A sulfur recovery unit will also be included.

TABLE 1

RIO BLANCO PROJECT SUMMARY

	PHASE I		PHASE II
	Stage I	Stage 2	
TIMING			
Construction	Apr. 1977-Aug. 1979	July 1980-Aug. 1982	Aug. 1982-Aug. 1985
Operation	Aug. 1979-Aug. 1982	Aug. 1982-Aug. 1985	Aug. 1985 and beyond
MINING			
Type	Open Pit	Open Pit	Open Pit
Ore Production	10,700 TPSD	21,400 TPSD	119,000 TPSD
Ore Haulage	Belt Conveyor	Belt Conveyor	Belt Conveyor
Overburden Haulage	Truck	Truck	Belt Conveyor
PROCESSING			
Retorting	TOSCO II	TOSCO II	Combination of TOSCO II & Gas Combustion/Paraho
Upgrading	Thermal Cracking	Thermal Cracking	Delayed Coking & Hydrotreating
Processed Shale Haulage	Truck	Truck	Belt Conveyor
PRODUCTS			
Pipelineable Shale Oil	4,500 BPSD	9,000 BPSD	-
Upgraded Shale Oil	-	-	55,800 BPSD
Sulfur	11 LTPSD	22 LTPSD	153 LTPSD
Ammonia (anhydrous)	-	-	232 TPSD
Coke	-	-	467 TPSD
Moisturized Processed Shale	11,000 TPSD	22,000 TPSD	118,500 TPSD
WATER DEMAND	1,390 AFY	2,370 AFY	10,000 AFY
POWER DEMAND	17.7 MW	28.8 MW	227 MW
PEAK EMPLOYMENT			
Construction	700	400	2,200
Operation	300	500	1,100

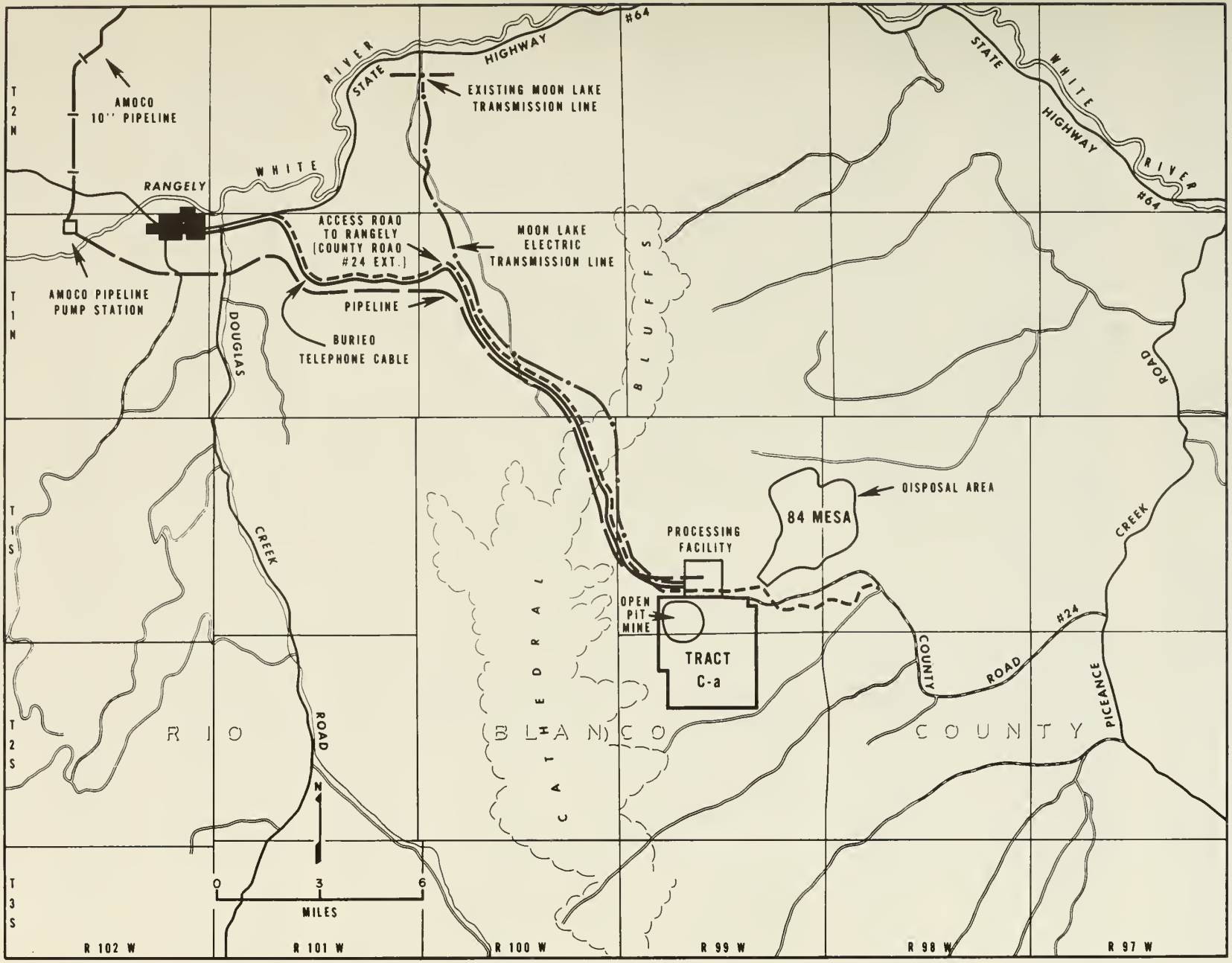


Figure 1

LOCATION OF PROPOSED RBOSP FACILITIES

Phase I - Stage 2 operations will begin three years later, during 1982, with the addition of a second TOSCO II retort, bringing total production to about 9,000 barrels per stream day (BPSD). Operation of the thermal cracking and sulfur recovery plants will continue. Construction of Phase II facilities will begin during Phase I - Stage 2 operations.

Phase II operations are scheduled to begin in mid-1985 using the best retorting technology available at that time, probably a combination of TOSCO II and gas combustion-type Paraho retorts, with a total processing capability of 119,000 tons per stream day (TPSD). Delayed coking and hydrotreating will be employed to produce upgraded shale oil at the rate of 55,800 BPSD. Phase II processing will also include hydrogen and oxygen production, high and low BTU gas production, sulfur and ammonia recovery, and coke production.

Open pit mining will begin in the northwest corner of Tract C-a and expand southeastwardly as ore production increases from 10,700 TPSD in Phase I - Stage 1 to 119,000 TPSD in Phase II. RBOSP selected open pit mining because it will allow maximum resource recovery from Tract C-a. Optimum development of the tract by open pit mining requires that the processing facility and processed shale and overburden disposal area be located off of Tract C-a as shown in Figure 1. Underground room-and-pillar mining would not require off-tract lands, but unless a feasible means of recovering oil shale from pillars is developed, nearly five times as much resource can be recovered from Tract C-a by open pit mining. From an environmental viewpoint, it is probable that one open pit operation will have less environmental impact in many ways than five room-and-pillar operations with their attendant disposal areas, roads, communications lines, power lines, and pipelines.

Selection of 84 Mesa as the location for processed shale and overburden disposal was based on an analysis incorporating environmental and operational comparisons of 16 potential disposal sites on and in the vicinity of Tract C-a. From an environmental standpoint, 84 Mesa ranked first among potential off-tract disposal sites and second overall. Operationally, 84 Mesa ranked first among all sites. Selection of the processing facility site was based on a similar analysis and on the additional considerations that it should be located: (1) in relatively close proximity to both the mine and the 84 Mesa disposal site; (2) on a topographic high rather than in a valley in order to enhance dispersion of stack emissions; and (3) on relatively level ground. A site at the north edge of Tract C-a was found to best satisfy these requirements.

Ore will be transported from the mine to the processing facility by belt conveyor during both Phases I and II. Processed shale and overburden will be hauled to disposal by trucks during Phase I and by belt conveyors during Phase II. After about 30 to 40 years of Phase II operations, it is expected that enough working space will have been created by mining to permit the backfilling of overburden and processed shale in the northwest portion of the open pit while mining continues in a southeasterly direction. As final slopes are established on the 84 Mesa disposal embankment, it will be progressively reclaimed. When backfilling the open pit begins, the disposal pile will have been contoured commensurate with existing topography and revegetated. Similarly, the backfilled portion of the open pit will be progressively reclaimed as operations proceed.

RBOSP's principal product (pipelineable shale oil in Phase I and upgraded shale oil in Phase II) will be transported by pipeline to Rangely, Colorado,

thence through an existing AMOCO pipeline to other connecting carriers for ultimate delivery to refineries in the West or Midwest; a possible exception to this plan is during Phase I when shale oil may be trucked to an existing refinery near Fruita, Colorado. By-products (sulfur, ammonia and coke) will be trucked from Tract C-a to rail facilities near Rifle, Colorado.

RBOSP employment during Phase I will be about 700 for construction, 300 for Stage 1 operations and 500 for Stage 2 operations. Phase II construction employment will peak at about 2,200 while the Phase II operating force will total about 1,100 permanent employees. Overall RBOSP employment is expected to peak at 2,700 during the period from mid-1982 to mid-1985 when both Phase I - Stage 2 operations and Phase II construction are underway.

RBOSP water requirements will vary from about 1,400 acre-feet per year (AFY) during Phase I - Stage 1 to some 10,000 AFY during Phase II. Current data indicate that all water requirements through Phase II can be supplied from ground water sources on Tract C-a. Normal mine dewatering operations should provide most of the required amount, but some supplementary wells (all on Tract C-a) may be necessary.

Project power demand will be about 18 MW during Phase I - Stage 1 operations and will increase to some 227 MW during Phase II. Moon Lake Electric Association will supply electricity to Tract C-a via a 230-KV transmission line from an existing line near the White River some 20 miles north of the tract. Mountain Bell Telephone Company will provide communications via a buried telephone cable from Rangely. Vehicular access to Tract C-a will be via Rio Blanco County Road 24 (Ryan Gulch Road) from the east and via an extension of this road from the tract to Rangely on the west. The power tranmission line, shale oil pipeline, telephone cable, and access road will be located, wherever possible in a common corridor between Rangely and Tract C-a.

If Phase II operations prove to be environmentally, technically and economically successful, RBOSP may elect to increase production above 55,800 BPSD. Current RBOSP estimates indicate that Tract C-a reserves are adequate to support a shale oil production of up to 300,000 BPSD. Such expansion could be achieved, for example, in two-125,000 BPSD increments.

Anticipating this possibility, RBOSP is already taking initial planning steps in areas where long lead times are necessary, the most important of which is securing rights to adequate surface water supplies. In addition to more water, increased production would also require a larger processing facility -- the Phase I and II processing facilities are located at a site where there is enough room for expansion. The need for additional off-tract lands for processed shale and overburden disposal is not anticipated since the void created during the first 30 to 40 years of Phase II mining should be sufficient to allow subsequent mining to stay ahead of backfilling operations, regardless of production rates.

Expansion beyond Phase II is treated only conceptually in this development plan because detailed planning for such expansion (excepting the acquisition of water rights) cannot begin until Phase II is underway. Ultimately, however, maximum recovery of resource from Tract C-a (and thus, maximum resource conservation) can only be realized by completely mining the tract. Furthermore, leaving exposed mining faces at the south and east boundaries of Tract

C-a will permit future developers on adjacent leases to continue open pit mining where RBOSP operations end.

BASELINE ENVIRONMENTAL AND GEOTECHNICAL CONDITIONS

As noted earlier, RBOSP has initiated extensive geotechnical and environmental baseline data collection programs on and around Tract C-a. These programs are designed to obtain data needed for engineering studies and development plans as well as fulfilling specific lease requirements.

Geotechnical data collection is subdivided into geologic and hydrologic programs. The geologic program is designed to provide detailed topographic, structural, stratigraphic, and resource data. The hydrologic program will provide data for determining baseline hydrologic conditions, aquifer characteristics, and for predicting the quantity of water expected to be produced during open pit mining.

The baseline environmental program designed by RBOSP complies with lease stipulations and, in addition, reflects the following goals: (1) to identify any potential data gaps that might exist in the lease stipulations and develop programs to correct such oversights; and (2) to evaluate lease stipulations and, if appropriate, suggest amendments that would best serve the environmental spirit enunciated in the lease.

The baseline environmental program was approved by the Area Oil Shale Supervisor following review and recommendations by the Oil Shale Environmental Advisory Panel. The program includes data collection in the following disciplines: air quality, meteorology, terrestrial and aquatic ecology, soil characterization, archaeology, and paleontology. Data from all elements are combined to describe overall ecological interactions. Incorporated in the design of these programs is a flexibility allowing response to changes indicated by the constantly expanding data base, without altering original objectives. For example, the study area in some programs was expanded from the original design to ensure coverage of potential disposal and processing facility sites. In addition to characterizing the physical and biological components of the Tract C-a study area, both qualitatively and quantitatively, the baseline environmental program will yield data for designing a monitoring program to measure changes caused by development.

ENVIRONMENTAL PROTECTION

RBOSP has developed specific environmental protection procedures to ensure compliance with lease provisions and environmental stipulations, and with all applicable Federal, State and local environmental protection and pollution control regulations. These procedures, or mitigation plans, are designed specifically for RBOSP's intended development of Tract C-a and will be modified, if necessary, as changing conditions are noted. The protection procedures described in this development plan cover the following topics:

Health and Safety
Air Quality Control
Water Quality Control
Solid Waste Control
Noise Control
Aesthetics
Abandonment
Fish and Wildlife Management
Land Rehabilitation
Oil and Hazardous Materials Control
Fire Prevention and Control
Protection of Objects of Historic and Scientific Interest

RBOSP has conducted an environmental assessment of proposed Tract C-a development. This assessment was based on the fact that the protection plans listed above will be implemented and that they will be modified as conditions dictate. The results of this assessment are that Tract C-a development alone will have slight, if any, impact on the functioning of the overall Piceance Creek basin ecosystem.

Various environmental monitoring programs will be conducted to provide a record of changes from conditions existing prior to development as established by the baseline data collection program, and to serve as a continuous check on compliance with lease provisions and applicable Federal, State and local environmental protection and pollution control regulations. Programs have been designed to monitor air quality, meteorology, hydrology, terrestrial and aquatic ecology, and revegetated areas. Analysis of data collected during the baseline program provides the basis for selecting those parameters that will most effectively indicate detrimental effects and, thus, the necessity for taking corrective action such as altering one of the environmental protection plans.

The monitoring programs will be initiated six months before development begins on Tract C-a. Monitoring will continue until the Area Oil Shale Supervisor determines to his satisfaction that environmental conditions consistent with Federal and State statutes and regulations have been established.

SOCIO-ECONOMIC PLANNING

Gulf and Standard recognized the potential social and economic impacts of oil shale development when the Tract C-a lease was acquired in January 1974. The two companies pledged then to cooperate with, support and participate in regional planning with the communities affected and with local, county, state and Federal governmental agencies.

A socio-economic plan is not legally required by the Tract C-a lease, but RBOSP officials and the Area Oil Shale Supervisor feel that such a plan is desirable. The overall objectives of RBOSP's socio-economic planning activities are to reduce negative impacts and to avoid the mistakes and resulting problems encountered in other areas experiencing significant population increases caused by new industry. RBOSP's plan to achieve these goals is described in a socio-economic report submitted separately from the detailed development plan.

STATE AND FEDERAL ACTIONS NEEDED BEFORE RBOSP CAN PROCEED

A variety of state and Federal actions are necessary before RBOSP can implement development of Tract C-a as described in this document. Specific actions needed are as follow:

- Area Oil Shale Supervisor approval of the detailed development plan
- Bureau of Land Management issuance of right-of-way permits for
  - pipeline to Rangely
  - road to Rangely
  - power transmission line
  - telephone cable
- BLM approval of use of 84 Mesa for disposal area
- BLM approval of use of offsite lands for processing facility
- Townsite lands are made available to Rangely by the BLM
- State appropriation for and construction of access roads
- State legislation to enable a town to receive and administer townsite lands
- An acceptable land trade with State Division of Wildlife for surface lands on and around Tract C-a
- State reclassification of air quality designation for area on and around Tract C-a
- Issuance of all required State and Federal permits

DDP ORGANIZATION AND USE

RBOSP's DDP consists of 11 sections comprising four volumes, as depicted in the chart on page 9. Volume 1 includes sections entitled "Project Background" and "Executive Summary." If one is interested in an overview of the development plan, Volume 1 is recommended.

Volume 2 is the largest of the four volumes. It describes baseline geological, hydrological and environmental conditions on and around Tract C-a. Volume 3 describes engineering plans for developing Tract C-a and includes sections on mining, retort feed preparation, processing, processed shale and overburden disposal and support facilities. Volume 4 describes RBOSP's environmental protection plans and also includes sections concerning environmental assessment and monitoring. The Confidential Volume, which is not publicly available, contains proprietary information concerning oil shale properties and ore reserve and cost estimates.

Except for the DDP abstract, a 3-number page numbering system is used throughout the development plan. Any given page number is unique in that it is not repeated elsewhere in the DDP. Page numbers are keyed to chapters within sections; page 3-4-45, for example refers to the 45th page of Chapter 4, (Hydrology) of Section 3 (Baseline Conditions).

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DETAILED DEVELOPMENT PLAN ORGANIZATION

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CHAPTER 1

INTRODUCTION

SECTION 3
BASELINE CONDITIONS

CHAPTER 1
INTRODUCTION

This section presents a comprehensive description of the environmental setting of Tract C-a and vicinity. The Code of Federal Regulations [30 CFR 231.10 C (2)] requires that "a description of the location and area to be affected by the operations" be submitted as part of the mining plan. In addition, the environmental stipulation (Section 1.C.1) of the lease requires that the Lessee shall compile data to determine conditions existing prior to any development operations and conduct a monitoring program before development begins. The lease and environmental stipulations specifically call out most of the programs detailed in the individual chapters of this section. Other programs are described in order to develop a complete picture of Tract C-a and vicinity before development begins. The lease also states that the baseline data shall be collected for a period of at least two consecutive full years, one full year of which shall be prior to the submission of the development plan. Also, all records of baseline data shall be submitted to the AOSS.

The air quality, meteorology, terrestrial ecology and aquatic ecology program are being conducted for a two-year period in order to establish the baseline. The information in this DDP covers the first year's work. The geology and hydrology programs are basically complete (except for required scheduled monitoring) and any additional work being done will be used to refine the baseline. The archaeology and paleontology programs have been completed. The trace metal and soil and overburden program are presently under way; field work has been completed, samples are being analyzed, and data reduction and final analyses are being done. The chapter on ecosystem interactions describes ecological interrelationships based on information gathered to date.

As mentioned above, all information gathered in the baseline program is submitted to the AOSS. The vehicle to present this information has been quarterly reports. RBOSP has designated these as Progress Reports. Progress Report 1 covered all baseline work done from the date of lease through September 30, 1974.

The next report spanned five months through February 28, 1975. Thereafter, reports were at three-month intervals, each covering a seasonal quarter of the year: Progress Report 3 (March-May 1974), Progress Report 4 (June-August 1974) and Progress Report 5 (September-November 1974). These reports include all field data and interpretive text. The reports have been submitted to the AOSS approximately 45 days after the end of the quarter in order to allow time for data reduction and interpretation. All information from these reports (except RBOSP proprietary information) is on open file at the AOSS office in Grand Junction, Colorado. The proprietary information is on file at the AOSS office, but is not available to the public.

In addition to Progress Reports, comprehensive summaries have been prepared for each report and have been available to interested parties. Detailed annual reports for the Geology, Hydrology, Air Quality, Meteorology, Terrestrial Ecology and Aquatic Ecology programs have also been prepared and are on file in the AOSS office.

The information presented in this section of the DDP is intended to be complete and comprehensive consistent with the information gathered to date; however, if more detailed information is desired or required, it will be necessary to refer to the Progress Reports and annual reports mentioned above.

CHAPTER 2

GENERAL DESCRIPTION OF PROJECT AREA

SECTION 3
BASELINE CONDITIONS

CHAPTER 2

GENERAL DESCRIPTION OF PROJECT AREA

2.1 LOCATION

Tract C-a is located in northwest Colorado, almost exactly midway and slightly south of a line between Denver and Salt Lake City. More specifically, the tract lies in the western third of Rio Blanco county, about 20 miles southeast of Rangely, 35 miles southwest of Meeker and some 55 miles due north of Grand Junction. The location of Tract C-a is further illustrated in Figures 3-2-1 and 3-2-2.

The specific lands covered by the Tract C-a lease amount to about 5,090 acres and are legally described as follow:

T. 1 S., R. 99W., 6th P.M.
Sec. 32: E1/2, E1/2W1/2
Sec. 33: All
Sec. 34: W1/2, SE1/4, W1/2NE1/4, SE1/4NE1/4
T. 2 S., R. 99W., 6th P.M.
Sec. 3: All
Sec. 4: All
Sec. 5: E1/2, E1/2W1/2 (incl. Lots 1, 2, and 3)
Sec. 8: E1/2
Sec. 9: All
Sec. 10: All

2.2 TOPOGRAPHY AND CULTURAL FEATURES

Tract C-a is situated on the west flank of the Piceance Creek basin about five miles east of the Cathedral Bluffs. The term "Piceance Creek basin," as used here, serves to identify an area of approximately 1,600 square miles that is bounded on the north by the White River, on the east by Government and Sheep Creeks, on the south by the Colorado River and Roan Creek, and on the west by Douglas and East Douglas Creeks.

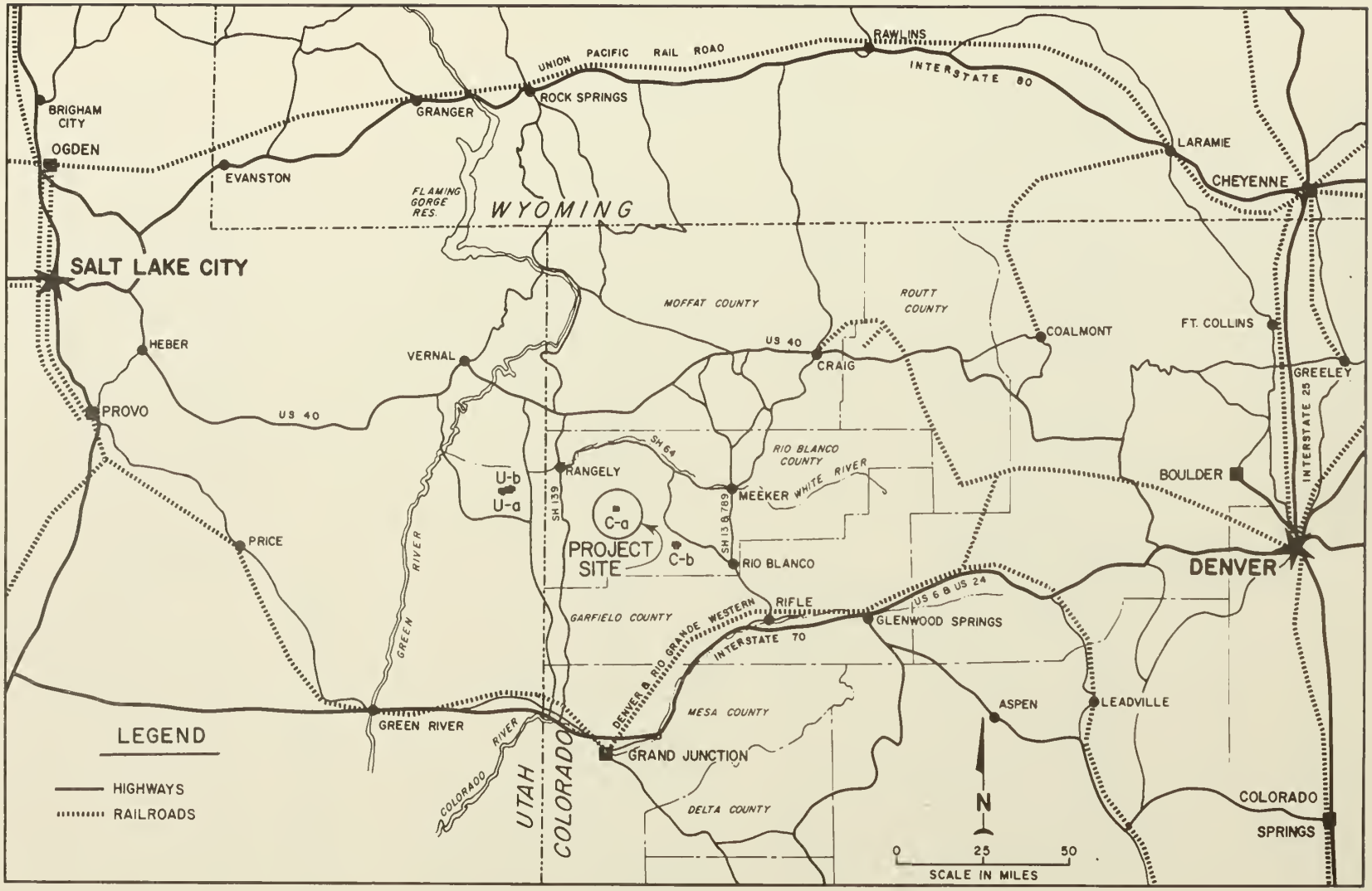


Figure 3-2-1

REGIONAL MAP SHOWING LOCATION OF TRACT C-a

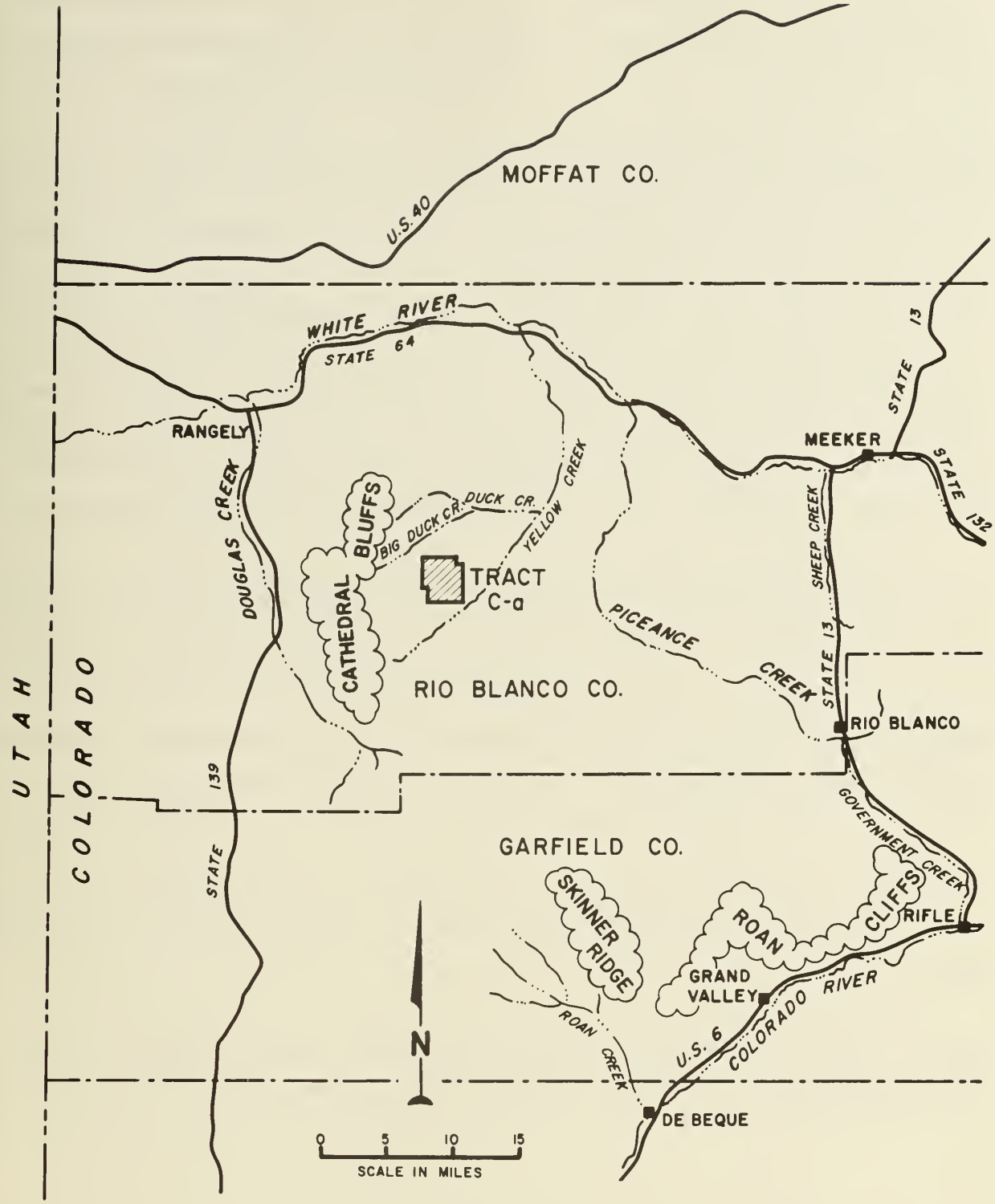


Figure 3-2-2
LOCATION MAP OF TRACT C-a

Geologically, the Piceance Creek basin is part of the Colorado Plateau. Because the basin was subjected to extreme vertical uplift in recent geologic time, it now appears, in relief, as a large shallow bowl lying atop the Roan Plateau. The edges of the basin lie near the rim of the plateau and, as a result, streams draining the exterior faces of the plateau are short, few in number, and exhibit steep gradients while Piceance and Yellow Creeks and their tributaries, which drain the basin proper, are longer and more gently sloping.

The basin's topography is characterized by a series of nearly parallel north and northeasterly trending ridges and valleys with local elevation differences ranging from 200 to 600 feet. Piceance Creek, Yellow Creek, and tributaries of Douglas and Sheep Creeks drain the northern part of the oil shale area and are tributaries to the White River. Parachute Creek, Government Creek and Roan Creek drain the southern part of the oil shale area into the Colorado River.

Tract C-a topography is characterized by northeast-trending subparallel canyons and ridges. Slopes of northern canyon walls are typically steeper than southern walls. Valley floors are narrow and ridges are broad and rounded; both slope gently northeastward. Surface elevations vary from about 6600 feet in Corral Gulch near the northeast corner of the tract to slightly more than 7400 feet on Airplane Ridge near the southwest corner of the tract. The average elevation difference between valley floors and nearby ridge tops is about 300 feet.

The valleys and ridges crossing Tract C-a originate to the southwest where they intersect the crest of Cathedral Bluffs which rise to elevations varying between 8400 and 8700 feet.

Most of Tract C-a is drained by Corral and Box Elder Gulches which eventually intersect Stake Springs Draw to form Yellow Creek about 3-1/2 miles east of the tract. Stake Springs Draw drains the far southeast corner of the tract.

Yellow Creek flows northeast from its origin but eventually curves to the northwest before emptying into the White River about 20 miles north of Tract C-a and at an elevation of some 5500 feet.

The first principal drainage north of Tract C-a is Duck Creek which flows into Yellow Creek about seven miles northeast of the tract. On the south, Ryan Gulch passes within about 2-1/2 miles of the southern boundary of Tract C-a before meeting Piceance Creek about 10 miles due east of the tract, where the elevation is about 6100 feet.

Few man-made features occur on or in the vicinity of Tract C-a. The Shields-Caldwell Hunting Camp near the confluence of Corral Gulch and Dry Fork are the only old buildings on the tract. In 1975, RBOSP built a small reception center in the extreme northeast corner of the tract. There are no other structures of any significance on Tract C-a. The remains of the 84 Ranch headquarters are located about three miles east of the tract. The nearest structure or site of special historic significance is the Old Ryan Gulch School about five miles east of the tract.

Elsewhere in the vicinity of Tract C-a, the area is interspersed with primitive roads and trails, a gas pipeline that crosses the far southeast corner of the tract, then parallels Stake Springs Draw for several miles before crossing the Cathedral Bluffs, a power transmission line some five miles west of the tract, several miles of fence at various locations, and several improved springs, check dams and small reservoirs. The nearest improved road is Rio Blanco County Road 24 in Ryan Gulch. The only paved highways in the vicinity are the Piceance Creek road to the east, the Douglas Pass road (State Highway 139) to the west, and State Highway 64 between Rangely and Meeker to the north. There are also several conventional natural gas wells scattered throughout the area southeast of Tract C-a.

Topography and cultural features on and around Tract C-a are further illustrated on Figure 3-2-3.

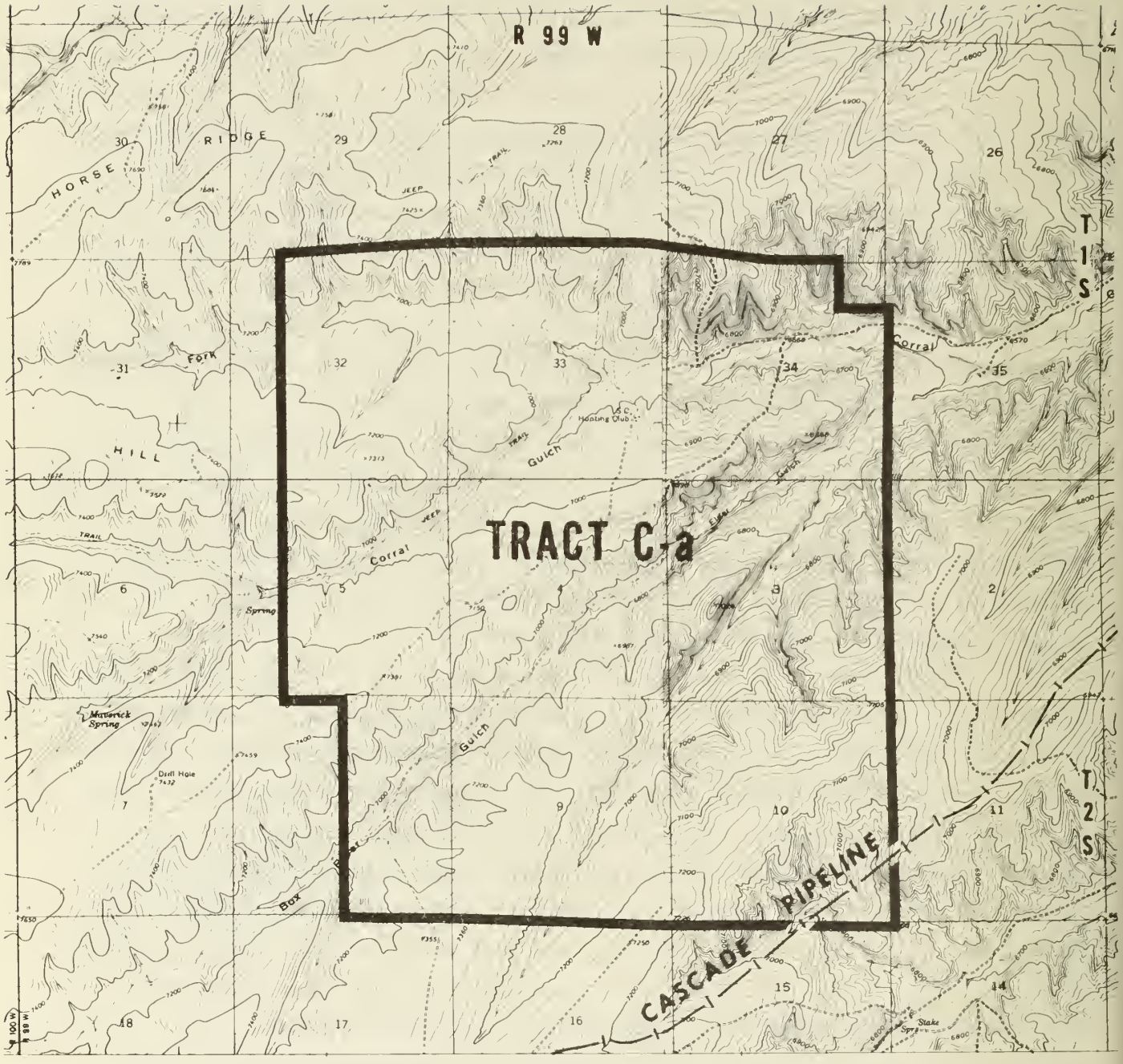


Figure 3-2-3
TOPOGRAPHY & CULTURAL FEATURES

2.3 LAND USE

The principal current activities in the Piceance Creek basin are ranching and stock grazing, big game hunting and conventional oil and gas field development. Haying is confined to drainage bottoms but stock grazing (primarily cattle) is conducted throughout most of the area.

Although the basin proper is relatively isolated and virtually uninhabited (except for the Piceance Creek valley), accessibility is good. Even so, big game hunting in October and November comprises by far the majority of the recreational use of the area. It is one of the most popular deer hunting areas in Colorado. Fishing on the other hand is nonexistent in the area including and immediately surrounding Tract C-a. The nearest sport fishing of any importance is on the White River and the extreme lower reaches of Piceance Creek. Fishing is far more attractive further up the river in the White River National Forest. Fishing and other recreational pursuits are of minor importance when compared to big game hunting.

While the Piceance Creek basin may be characterized as a beautiful and relatively unspoiled natural setting, it is not particularly spectacular scenery, nor does it contain any exceptional natural, archaeological, or historical sites.

The fact that the Piceance Creek basin is not attractive to tourists and others pursuing outdoor recreational experiences is also attributable to the close proximity of many well known areas such as:

- Dinosaur National Monument
- Black Canyon National Monument
- Flaming Gorge National Recreation Area
- White River National Forest
- The Colorado Rockies in general

2.4 OFF-TRACT AREAS NEEDED FOR DEVELOPMENT

In addition to the area covered by Tract C-a and various utility and access corridors leading to the tract, other off-tract lands will be needed for the processing facility, overburden and processed shale disposal area, and a water control reservoir.

The processing facility will require a relatively small area during the early years of development but will eventually cover about 250 acres. The area selected for the processing facility is in Section 28, T1S, R99W, north of and adjacent to the tract. The overburden and processed shale disposal area will be located on 84 Mesa northeast of the tract. Phase I disposal operations will require about 375 acres; in Phase II, the pile will eventually comprise approximately 4,000 acres, including the 370 acres required for Phase I. The water control reservoir needed during Phase II will occupy an area of about 260 acres in Corral Gulch about 2-1/2 miles east of the tract. The area for these off-tract uses are shown on Figure 3-2-4.

Figure 3-2-5 depicts surface ownership in the areas planned for the processing facility, overburden and processed shale disposal area, and the processing facility. The northeast corner of Tract C-a contains 240 acres where the surface and some mineral rights are not controlled by Rio Blanco through its Federal oil shale lease. This ownership is also depicted on Figure 3-2-5. In addition, Tract C-a and the off-tract areas requested (except for certain patented lands) are entirely covered by Federal oil and gas leases. Those leases which are within Tract C-a are discussed in Chapter 3 (GEOLOGY) of this section.

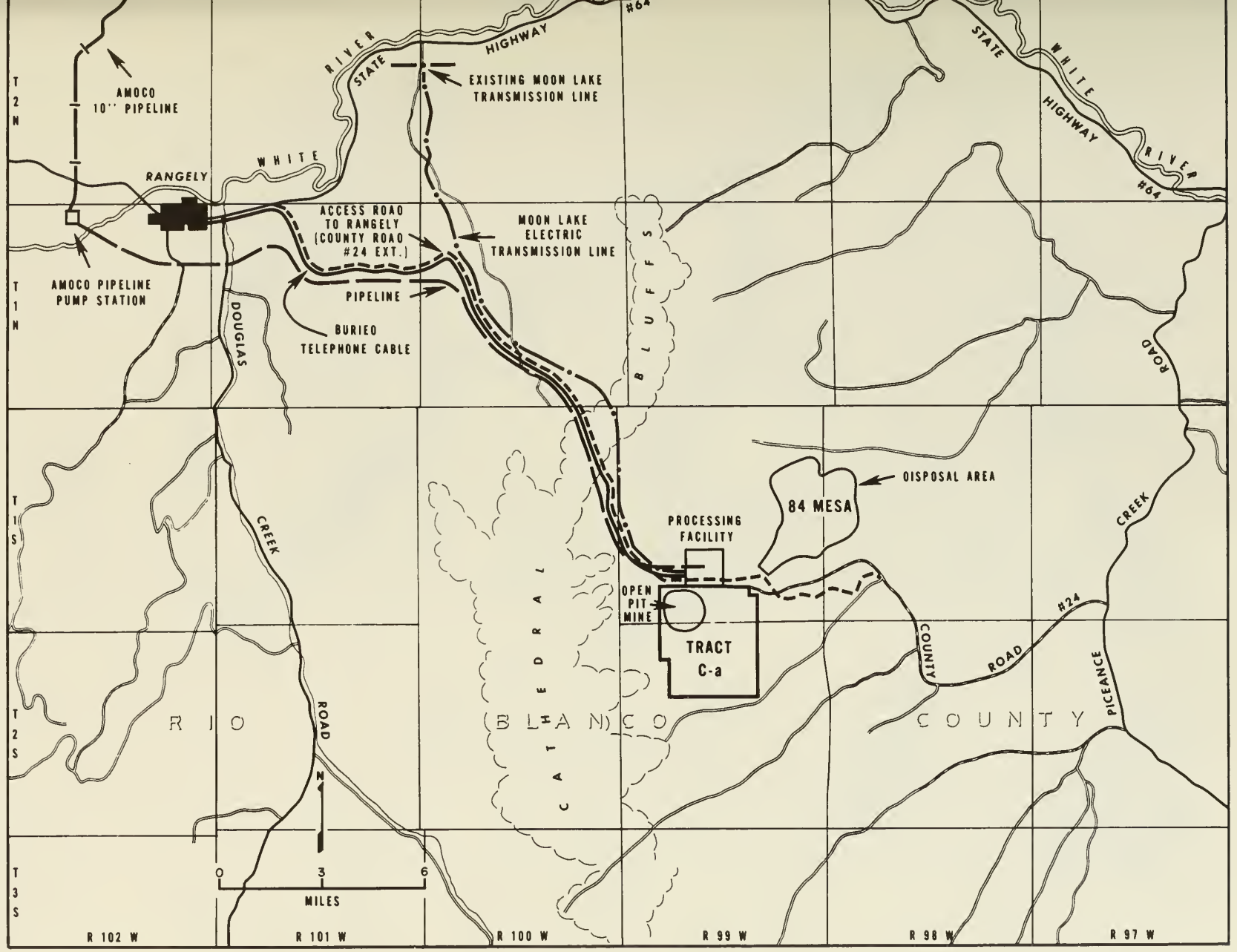


Figure 3-2-4

LOCATION OF PROJECT FACILITIES

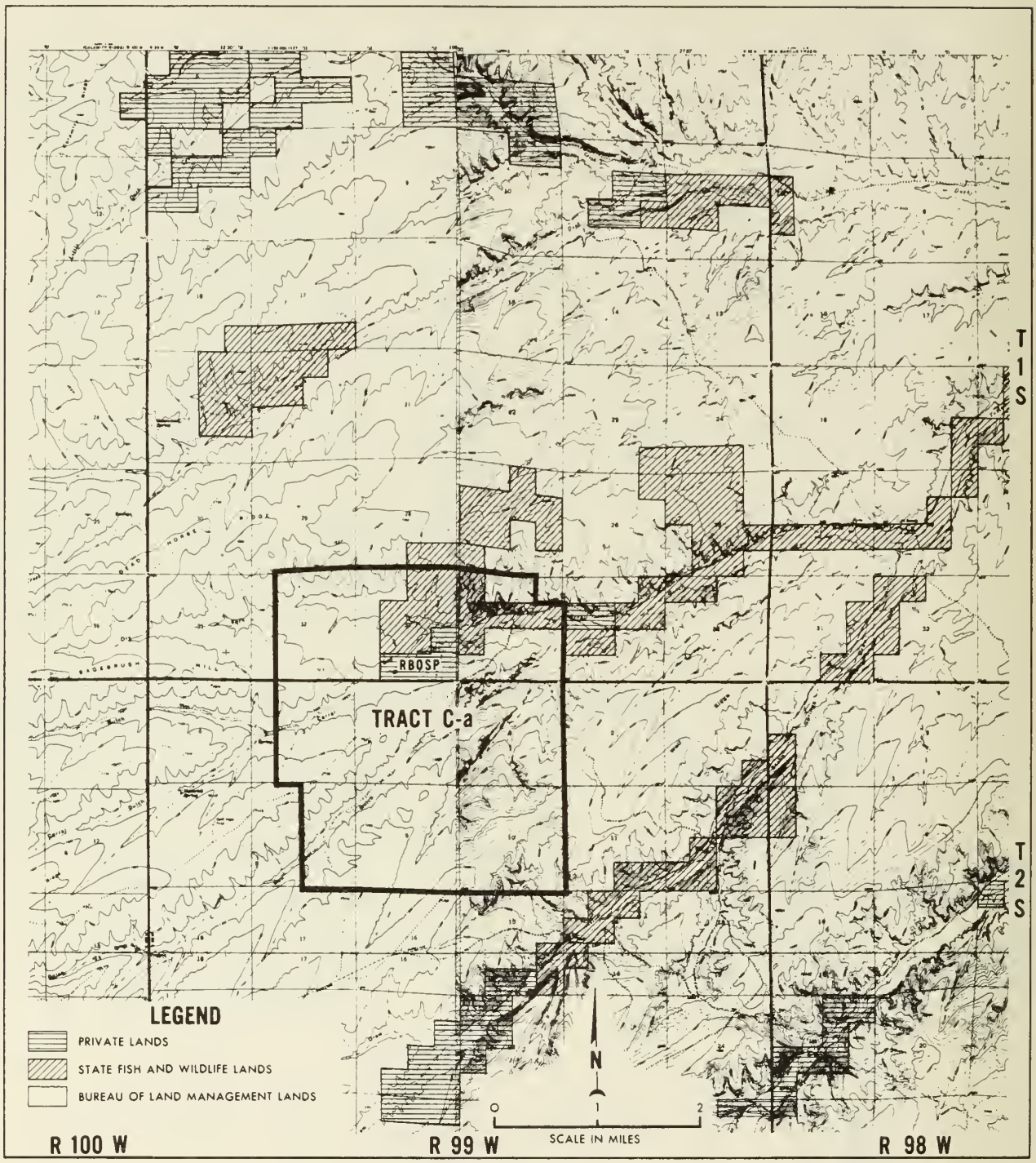


Figure 3-2-5
SURFACE OWNERSHIP

CHAPTER 3

GEOLOGY

SECTION 3
BASELINE CONDITIONS

CHAPTER 3
GEOLOGY

In May, 1974, Gulf-Standard (Indiana) submitted to the Area Oil Shale Supervisor their Tract C-a Exploratory Plan which specified the various data gathering programs and engineering studies considered necessary to formulate the Detailed Development Plan. Section 5 of the G-S Exploratory Plan presented a summary report of the tract's geology as then known or interpreted and listed additional geologic investigations designed to more fully evaluate its structure, stratigraphy and mineral resources.

On June 27, 1974, the AOSS conditionally approved both the G-S Exploratory Plan's Geologic Exploration Plan and Subsurface Hydrology Plan. Attached was a list of 14 conditions which Gulf-Standard accepted. On August 27, 1974, the AOSS amended three of the previous conditions of approval, which pertained to analysis for trace elements, radioactivity and chemical constituents in ground water, oil shale and overburden. These revisions were also accepted by Gulf-Standard.

The purpose of this geologic chapter is to:

- Review the data gathering programs related to the additional geologic investigations as outlined in the G-S Exploratory Plan. The AOSS has been kept formally advised periodically as to the status of these activities in RBOSP Progress Reports 1 thru 5 which cover activities in each seasonal quarter from 3/1/74 to 11/30/75. These reports also list data compiled by these activities which have been transmitted to the office of the AOSS.
- Incorporate the results of the additional programs into previously existing control and present a detailed updated version of Tract C-a geology as now known or interpreted. Pertinent information from published sources is also included.

All additional geologic investigations as outlined in the G-S Exploratory Plan are now complete with the exception of:

- A limited amount of surface geologic mapping: All field work was terminated on December 11, 1974, when heavy snow fall in the area forced its suspension for the season. At that stage, the mapping within Tract C-a was about 70-80% completed. Rio Blanco planned to complete the surface geologic mapping program during the first half of 1975. However, in March, 1975, Rio Blanco elected to defer completion of the program until priorities were defined as to where and what type of additional surface geologic control was yet needed based on mining and engineering studies then in progress. After evaluating all available photogeologic, surface geologic and subsurface geologic data, Rio Blanco decided sufficient control was already compiled to define the tract's major geologic characteristics and formulate the DDP. The unfinished surface mapping program was therefore cancelled to be replaced by field-checking of the unfinished areas as required (see Surface Geologic Mapping, item 3.1.C).
- Incorporation of Fischer assays of core held for rock mechanics tests in 8 G-S core holes and check re-assays in two G-S core holes: Of the approximately 2150' of core involved in the above programs, assays are now complete on about 1450' of core. This new assay data will be incorporated into tract control with appropriate revised maps and cross sections submitted to the AOSS (see Laboratory Analyses, item 3.1.F).
- A detailed review of the questionable structural data resulting from the seismic program: At present, this data is in "hold status" because the subsurface structure shown by the seismic program significantly conflicts with known structure clearly defined at the surface. Extensive seismic record processing required to separate surface noise from reflected energy may have resulted in erroneous portrayal of subsurface structure. Considerable detailed evaluation of the basic field records will be necessary to determine its usefulness and reliability (see Seismic Exploration Program, item 3.1.G).

Data yet forthcoming as listed above may result in some minor revision of the Tract C-a geology as currently defined. However, the tract geology presented in this report is considered representative of its major structural, stratigraphic and mineral resource characteristics.

It should be recognized, however, that future supplemental geologic programs, particularly those furnishing more subsurface structural control, may result in significant revisions of structure in local portions of the tract. These revisions can be expected to be most pronounced where additional structural control is obtained in the vicinity of fault zones. Further, tract development will expose to view even more structural data in open pit walls and/or underground mines.

Whatever the source, new data will be evaluated and incorporated into present geologic control as it is obtained. Revisions in the tract's geologic framework will be made periodically as required with copies furnished to the office of the AOSS.

3.1 REVIEW OF DATA GATHERING PROGRAM

A. Aerial Photography - Approximately 392 square miles of color and color-infrared aerial photography was completed in September, 1974, by Bovay Engineers, Inc.-IntraSearch, Inc. The area overflown is shown in Figure 3-3-1 and encompasses the originally planned 380 square miles plus an additional 12 square miles on its northwest border in the vicinity of the Spring Creek headwaters immediately downslope from Cathedral Bluffs. This additional area was overflown to provide new photo coverage over a potential area of interest for waste disposal.

Prior to overflight, survey parties established necessary ground control including the location and appropriate paneling of existing section and quarter-section corners (monuments) so that they would be readily identifiable on the new photos.

Color photography was obtained at both 1" to 3000' and 1" to 1000' scale. Color-infrared photography was obtained at 1" to 1000' scale.

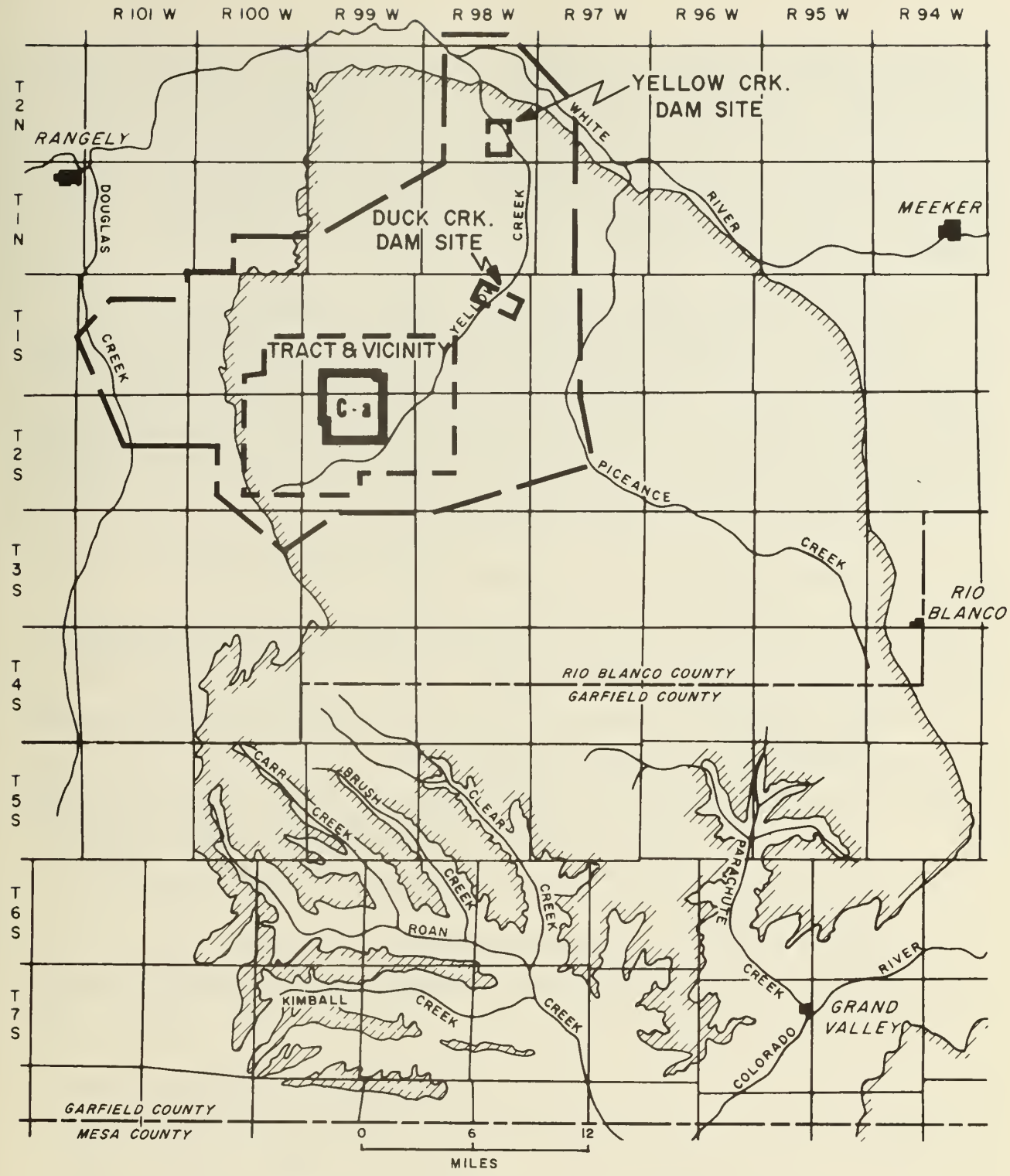
The total overflight area of 392 square miles far exceeds that required for detailed topographic mapping and geologic evaluation of the 85 square miles covering Tract C-a and Vicinity, Duck Creek Dam Site and Yellow Creek Dam Site as outlined in the G-S Exploratory Plan. This relatively large overflight area was designed to provide new photo coverage as base control for other studies including off-tract facilities, corridor location, surface hydrologic and environmental investigations. The photographs obtained are on file at the Rio Blanco office.

B. Photogeologic Mapping - Trollinger Geological Associates used the new aerial photography for their photogeologic interpretations. Three areas totalling about 85 square miles were critically examined with particular emphasis on the definition of surface fault and joint-fracture systems. These three areas are identified as Tract and Vicinity, Duck Creek Dam Site and Yellow Creek Dam Site on Figure 3-3-1 .

Because Bovay Engineers, Inc., was at this time only in the initial stages of contructing new detailed topographic maps, TGA posted their photogeologic interpretations on 1"-1000' scale topographic base maps composited and expanded from existing 1"-2000' scale USGS 7.5 minute quadrangle topographic maps.

Rio Blanco furnished TGA with middle A-groove datums in on-tract core holes and in available off-tract core holes and conventionally drilled wells. TGA incorporated this subsurface control into their photogeolgic interpretation of the Tract and Vicinity area by form-line contouring their photogeologic control at this structural horizon.

TGA completed their preliminary photogeologic map of the Tract and Vicinity area in October, 1974. Their final report including maps of all three areas was completed in November, 1974. These data provided the base control for subsequent surface geologic mapping by Amuedo and Ivey.



APPROXIMATE OUTLINE OF GREEN RIVER FORMATION

OVERFLIGHT AREA FOR AERIAL PHOTOGRAPHY

AREAS (3) FOR: PHOTOGEOLOGIC, SURFACE GEOLOGIC & DETAILED TOPOGRAPHIC MAPPING

Figure 3-3-1

REGIONAL MAP, PICEANCE CREEK BASIN

C. Surface Geologic Mapping - Amuedo and Ivey commenced their surface geologic mapping program immediately upon receiving TGA photogeologic data and aerial photos. A&I overlaid with clear film all photos on which TGA photogeologic data was posted to prevent TGA's work from destruction or alteration with field use. In this way, TGA and A&I interpretations were kept separate for subsequent review by Rio Blanco.

All field work was terminated on December 11, 1974, when heavy snow fall in the area forced its suspension for the season. At that stage, surface geologic mapping within Tract C-a was about 70-80% completed (A&I, 1975-B) and the mapping of Yellow Creek Dam Site was completed (A&I, 1975-A). Because geologic conditions were found very favorable at the Yellow Creek Site, surface mapping of the Duck Creek Site was postponed indefinitely.

A&I's geologic mapping of Tract C-a involved the following tasks:

- Field-check all TGA photo-defined or suspected fault and joint-fracture systems.
- Determine the orientation of faults and the amount and direction of displacement associated with them.
- Map surface structure with plane-table and alidade methods utilizing laterally persistent key beds. Lower the defined surface structure to the middle A-groove horizon by means of key bed(s) to middle A-groove isopachs.
- Obtain surface joint orientation data.
- Measure several stratigraphic sections to define the general lithology of the tract's surface rocks.

A&I originally posted all their Tract C-a field data on an expanded 1"-500' scale topographic base map constructed by Rio Blanco from existing 1"-2000' scale USGS 7.5 minute quadrangle maps. In February of 1975, the new 1"-500' scale Bovay topographic base map of the tract was completed. At Rio Blanco's direction, A&I transferred the TGA photogeology, the subsurface middle A-groove datums and the A&I surface geologic mapping to this new base map.

Rio Blanco planned to have A&I complete their surface geologic mapping program in the Tract C-a and Vicinity area during the first half of 1975. However, in March, 1975, Rio Blanco deferred all further surface geologic mapping until priorities were defined as to where and what kind of additional surface geologic control is yet needed, if any, based on mining and engineering studies. After evaluating all available photogeologic, surface geologic and subsurface geologic data, Rio Blanco decided sufficient control was already compiled to define the tract's major geologic characteristics and formulate the DDP. Additional surface geologic mapping would not result in a major revision of the tract's structure as currently known but only further refine it. A&I were instructed to finalize all data that had been compiled to that point and submit them to Rio Blanco. The last of their work, including written reports with conclusions and recommendations, was received in March for the Yellow Creek Dam Site and in April for Tract C-a and Vicinity.

D. Topographic Mapping - Bovay Engineers, Inc., completed detailed topographic map construction in February, 1975. These maps were compiled by photogrammetric methods from the newly flown 1" to 1000' scale aerial photography. Map horizontal control surveys are referred to the Colorado State Plane Coordinate System, North Zone, modified to a 7200' datum. Lambert Conformal Conic Projection vertical control surveys are related to mean sea level.

The three areas, Tract C-a and Vicinity, Duck Creek Dam Site and Yellow Creek Dam Site, shown on Figure 3-3-1, encompassing a total of about 85 square miles, were mapped on 89 map sheets at a horizontal scale of 1" to 200' and a contour interval of 5'. The 84 map sheets comprising the Tract C-a and Vicinity area, about 81 square miles, were photographically reduced to a horizontal scale of 1" to 500' and composited into a set of 9 map sheets with Tract C-a located in the center sheet of a three by three map sheet pattern.

E. Core Hole Program - The core hole program in the G-S Exploratory Plan originally proposed the drilling of 15 new core holes on Tract C-a supplementing the 12 pre-sale tract core holes (6 Cameron, 3 Amoco and 3 TOSCO). However, two of the proposed core hole locations were found topographically unfavorable

by representatives of BLM, Meeker, when jointly field-checked by BLM and G-S personnel. These two core holes (original locations G-S 3 and 4) were subsequently eliminated from the program. Two other proposed core holes (original locations G-S 2 and 5) were moved to compensate for the loss of the two core holes and still maintain a good core hole "spread" across the tract. The new core hole locations were designated G-S 2-3 and 4-5 with a revised program of 13 new core holes rather than the originally proposed 15. AOSS approval of the revised core hole program was received on June 27, 1974. Figure 3-3-2 shows the location of all core holes on Tract C-a.

The core hole program was commenced on July 3, 1974 and completed on October 27, 1974. Late in the program, Rio Blanco requested AOSS approval to reduce overburden coring in core holes G-S 10, 11, 13 and 14, a total of about 2100'. Overburden data obtained up to that point was considered representative of the tract and additional coring would only be redundant. In addition, the reduced overburden coring lowered the cost of the program and expedited its completion prior to the forthcoming winter season. This approval was obtained on September 11, 1974.

Numerous contractors were involved in the program. Limnetics, Inc., and Denver University provided biological and archeological clearance, respectively, for the core hole sites and their access roads prior to any earth moving. Amoco Production Company furnished considerable logistical support throughout the program. The drilling contractors were Carmack Drilling Company and Dreiling Drilling, Inc., each furnishing one rig. McDowell-Smith Associates surveyed the core hole locations and established their ground elevations. Amuedo and Ivey furnished on-site geological personnel to photograph the core, describe and log its lithologic and structural characteristics, and appropriately mark and box it for shipment off tract. A&I also collected gas samples for analysis generally at the A-groove, B-groove and total depth. Hydrologic data was collected by Wright Water Engineers during the drilling program which is discussed in detail in Section 3, Chapter 4. Schlumberger Well Services and Birdwell Division of Seismograph Service Corporation were contracted for geophysical (mechanical) logging. Core Laboratories, Inc., transported core to Rifle for Fischer assay, preparation of samples for other analyses and

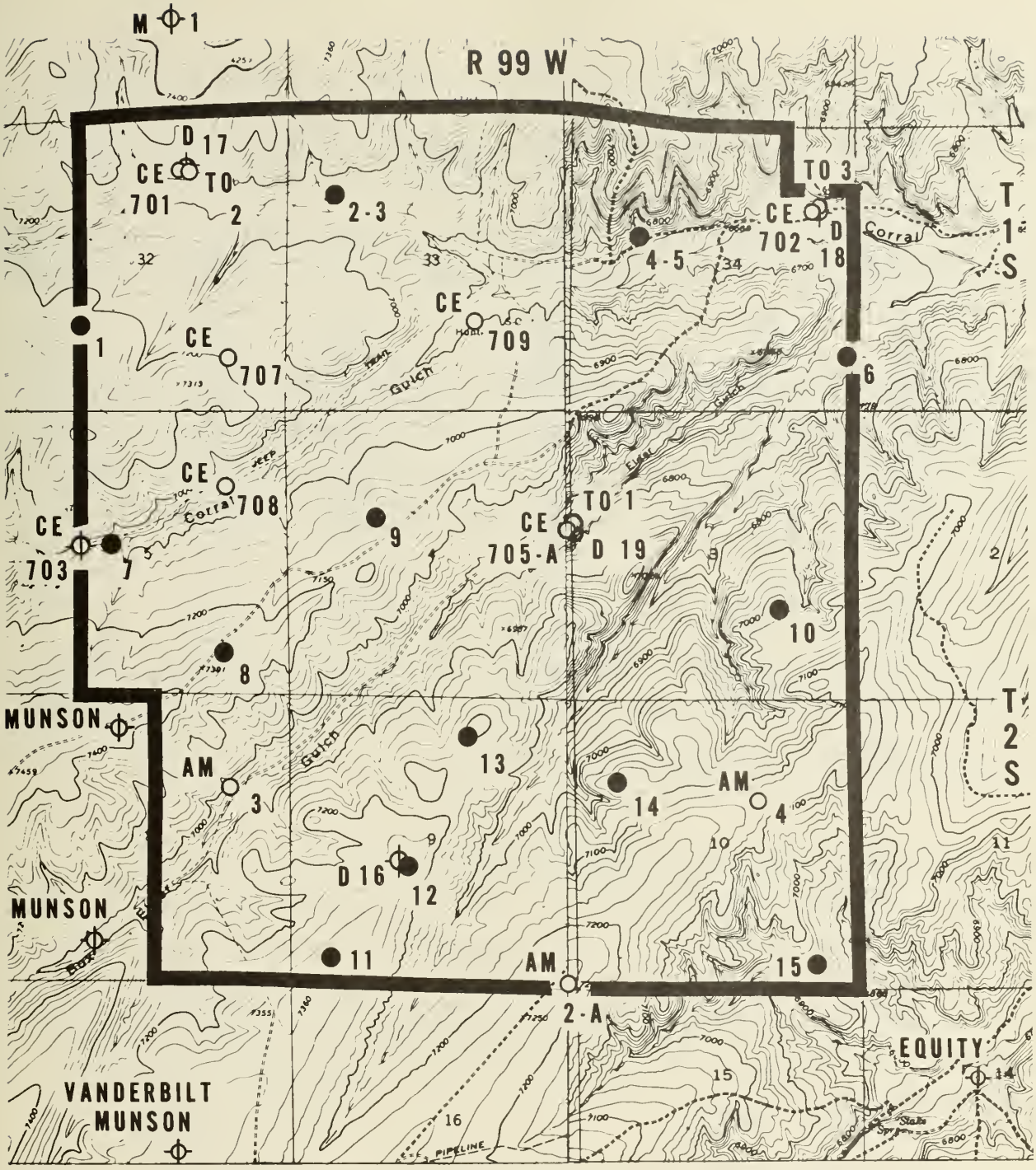


Figure 3-3-2

CORE HOLE LOCATIONS, TRACT C-a

storage. They also analyzed the gas samples collected. Late in the program, Core Lab installed H_2S gas detectors at coreholes G-S 11, 14 and 15 and the 4 D-holes drilled for hydrologic testing to obtain data on its concentrations.

Core cut in all G-S core holes was 3.5" in diameter. Drilling fluid was air-mist rather than mud to minimize formation damage and provide optimum hydrologic test conditions.

All efforts were made to obtain maximum core recovery. Table 3-3-1 summarizes the program's core recovery on a hole by hole basis. The two core holes with the lowest percent core recovery are G-S 9 and 12, both of which were intentionally located within fault zones where highly fractured shale resulted in lower core recovery.

Continuous borehole directional surveys run in core hole G-S 8 and in G-S 15 were computer-analyzed by Amoco Production Company, Denver. Borehole positions, relative to hole point of origin (surface location), were computed at stations every 50' from base surface casing to total depth. Table 3-3-2 is a brief summary of the analysis results.

Both core holes drifted predominately westward with a lesser north-south component and reflects their tendency to "climb" subsurface structure. This is characteristic of most, if not all holes, whether conventionally drilled or cored. It is assumed that all other core holes on Tract C-a deviated in a similar manner. For interpretive purposes, the holes are assumed vertical and representative of the thickness of the stratigraphic section each penetrated, requiring no correction.

F. Laboratory Analyses

1. Fischer Assays - Core Laboratories, Inc., ran Fischer assays of approximately 2' core increments concurrently with the core hole drilling program and completed assays of all "released" core (defined below) on December 31, 1974. These assays were performed at temporary lab facilities

Table 3-3-1

SUMMARY OF CORE RECOVERY; G-S CORE HOLE PROGRAM
TRACT C-a

G-S CH No.	TD	Core Cut	Core Rec.	Core Lost	% Core Recovery
1	1,404	1,360.7	1,317.1	43.6	96.8
2-3	1,424	1,352.5	1,240.1	112.5	91.7
4-5	1,663	1,615.5	1,486.2	129.3	92.0
6	1,781	1,624.5	1,565.0	59.5	96.3
7	1,200	1,159.7	1,148.2	11.5	98.9
8	1,616	1,548.2	1,458.6	89.6	94.2
9	1,600	1,556.4	1,357.5	198.9	87.2
10	1,902	1,550.3	1,455.5	94.8	93.9
11	1,886	1,495.4	1,404.9	90.9	93.9
12	1,800	1,759.0	1,588.6	170.4	90.3
13	1,751	1,481.0	1,387.2	93.8	93.7
14	1,794	1,546.6	1,421.1	125.5	91.9
15	1,835	1,794.4	1,690.9	103.5	94.2
Totals	21,656'	19,844.6	18,520.8	1,323.8	93.3 (Avg.)

Table 3-3-2

HOLE DEVIATION SUMMARY

	G-S 8	G-S 15
Max. hole drift from vertical (degrees):	3.6	2.2
Hole displacement at TD from surface location (feet, direction from true north):	50.1 W 5.1 S	45.0 W 11.0 N
Net Horizontal Displacement:		
Distance (feet):	50.4	46.3
Bearing:	S84°W	N76°W
Total depth, driller (feet):	1616.0	1835.0
Deepest station analyzed (feet):		
Log measured:	1600.0	1816.0
Corrected vertical:	1598.8	1815.3
Difference:	1.2	0.7

established in Rifle specifically for the G-S core hole program to minimize core transport distance and expedite the total assay program. Core Lab also maintained storage facilities for Rio Blanco in Rifle where core, crushed core surplus to that required for assay retort feed, and spent shale derived from the assays are retained.

Shale oil generated from the individual assays was saved and composited into rich and lean zonal samples. Intervals for these zones were designated by Rio Blanco based on gamma ray-density logs (hereafter called density logs) and furnished to Core Lab prior to assaying. The composite shale oil samples were shipped to Gulf Research and Development Company for analysis to determine if shale oil characteristics vary from zone to zone.

"Released" core is that which Rio Blanco directed Core Lab to assay as received for resource information. "Unreleased" core is that which Rio Blanco directed Core Lab to segregate from their normal assay stream and retain for rock mechanics tests. This testing program requires full unslabbed core for various tests. Selected intervals in seven core holes, G-S 1, 2-3, 4-5, 6, 8, 11 and 15, together with all core in G-S 13 were reserved for this testing program.

Oil shale grades estimated from density logs by Amuedo and Ivey are currently being used for resource data within the selected intervals for which assay data is not available in the seven G-S core holes listed above and G-S 13 is essentially being treated as a "non-existent" core hole for resource calculations. As the rock mechanics testing is completed in each core hole, this core is released for resource data assaying. Grades now estimated by A&I from density logs will be replaced by lab-assays and G-S 13 will be incorporated into tract resource control.

Rio Blanco's construction of isograde-isopach contour maps of 19 discrete oil shale zones and the main oil shale interval (middle A-groove to Blue marker) located certain intervals in two core holes, G-S 4-5 and 6, which were suspected of questionable GPT grade data. Closely spaced grade contours required to honor all available control strongly suggested anomalous grade data. Core Lab has run re-assays in these intervals and confirmed the presence of erroneous original assay data.

Preliminary review of some of the re-assays in these two core holes indicates some are higher and others are lower than the original assays. Adjustment of the tract's oil shale resources in the vicinity of these two core holes will be required. The adjustment may result in appreciable average grade changes in some oil shale zones, but it should not result in a major revision of the tract's oil shale resources as presented in this report. However, the re-assay data will be incorporated into the tract resource control (computer mineral inventory) and appropriate revisions made to the tract resource estimates. Revised resource estimates, including new zonal isograde-isopach maps will be furnished to the AOSS as this work is completed.

2. Acid Extractable Alumina - In eight core holes spaced across Tract C-a (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15), Rio Blanco selected intervals for quantitative analysis of acid extractable alumina in spent shale. These intervals were selected prior to Fischer assaying based mainly on rich and lean oil shale zonation as evidenced on density logs and modified by significant lithologic changes on A&I core description logs. No analysis interval was allowed to exceed 100' in thickness. Interval boundaries were furnished to Core Lab, Rifle, who composited representative samples of spent shale for each interval as the Fischer assays were run. These samples were forwarded to Core Lab, Casper, where the extractable alumina analyses were performed using the techniques outlined in USBM Report of Investigations No. 7286 (1969). All analyses in the eight G-S core holes were completed on January 17, 1975.

3. Nahcolite - Minor amounts of nahcolite were located in all G-S core holes except G-S 2-3 in which it is totally absent. Where nahcolite was identified on Amuedo and Ivey core description logs, Core Lab, Rifle, prepared samples for nahcolite quantitative analysis from surplus crushed fresh core, excess to that required for their Fischer assay feed. These samples were forwarded to Core Lab, Casper, where the analyses were performed using the techniques outlined in USGS Professional Paper No. 750B (1971). All analyses were completed on January 30, 1975.

One thin nahcolite-bearing shale interval in core hole G-S 13 has not yet been analyzed. As stated above (item 3.1.F.1) all core in this core hole is retained for rock mechanics tests which require full unslabbed core.

4. Trace Elements - At Rio Blanco's request and well in advance of any actual lab work, Core Lab contacted the U. S. Environmental Protection Agency, Denver, to determine what quantitative analysis techniques would be appropriate for the trace elements listed in Table 3-3-3 in both fresh and spent oil shale. Core Lab used the techniques listed as recommended by the EPA by letter dated July 23, 1974. Specific references describing these techniques are cited in Rio Blanco Oil Shale Project Progress Report No. 2 (Feb., 1975).

In the same eight core holes spaced across the tract which were analyzed for extractable alumina (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15), Rio Blanco selected intervals for trace element quantitative analysis of both fresh and spent shale. To minimize sample handling and preparation, the intervals selected in each of the eight core holes were the same as those selected for extractable alumina analysis of spent shale. In addition, intervals were selected in overburden rocks containing no oil shale for trace element analysis in fresh rock samples only.

Table 3-3-3

TRACE ELEMENT AND ANALYSIS TECHNIQUE

Element	Analysis Technique
Antimony	Atomic absorption spectrophotometry
Arsenic	Atomic absorption spectrophotometry
Boron	Visible spectrophotometry
Cadmium	Atomic absorption spectrophotometry
Fluoride	Specific ion electrode
Mercury	Flameless atomic absorption spectrophotometry
Selenium	Fluorometry

Interval boundaries were furnished to Core Lab, Rifle, who composited representative samples of fresh crushed shale, spent shale and fresh overburden intervals as the Fischer assays were run. These samples were forwarded to Core Lab, Casper, where the trace element analyses were performed. All analyses in the eight G-S core holes were completed by January 17, 1975.

Colorado School of Mines Research Institute was subcontracted by Core Lab to identify the trace element-bearing minerals. Preliminary identification of these minerals in both fresh and spent shale samples from core holes G-S 2-3 and 7 was completed on February 28, 1975, using X-ray diffraction and element partitioning techniques.

G. Seismic Exploration Program - About 10 miles of shallow high resolution seismic line was planned within Tract C-a as outlined in the G-S Exploratory Plan. Petroleum Geophysical Company, the seismic contractor, commenced experimental shooting in early December, 1974. After two unsuccessful attempts to obtain reliable data, the program was terminated by Rio Blanco on January 31, 1975.

The first experimental shooting attempt consisted of two days of spot shooting with 200% coverage and failed to define reliable mappable reflections within the shallow target oil shale interval. The second involved 1.5 miles of continuous 600% coverage line along Corral Gulch crossing a well-defined surface fault system (graben). Considerable seismic record processing with various filters was required in an effort to separate surface noise from reflected energy and optimize the shallow reflections. This processing may have resulted in an erroneous portrayal of subsurface structure because the seismic profile obtained does not agree with well defined structure as observed at the surface. This problem has been discussed with Gulf and Standard (Amoco) geophysicists. The concensus is that the seismic data requires additional interpretation and is of little value in its present form because of the low confidence level currently attributed to it. Considerable detailed evaluation of the basic field records will be necessary to determine the usefulness of the seismic data. Until this evaluation is made, the data will remain in "hold status" and will not be incorporated into tract structural control.

PGC prepared a brief written report describing the techniques used in their experimental shooting. This report was received on February 26, 1975.

H. Geologic Evaluation (Data Compilation) - As new stratigraphic, structural and resource information was obtained from the various phases of the G-S Exploratory Plan's geologic portion (Sec. 5), it was continuously incorporated into existing geologic control on a rough draft basis to monitor both the progress and results of the various data gathering activities. The one exception to this data incorporation is the results of the seismic program which remain in "hold status" for reasons previously cited.

Two key maps, middle A-groove structure and main oil shale interval isopach (middle A-groove to Blue marker) were maintained throughout the course of the G-S core hole program to monitor the newly acquired subsurface stratigraphic and structural data and readily define any major variations from that anticipated based on available pre-existing on-tract and off-tract control. The only major "surprises" occurred in core holes G-S 9 and 12 which were both intentionally drilled in downthrown blocks of fault zones (graben). Both core holes encountered the middle A-groove horizon at a structural datum considerably higher than anticipated. The data from these core holes will be discussed more fully under Structure (item 3.3.B).

1. Stratigraphic - Rio Blanco initiated the detailed stratigraphic data compilation within Tract C-a in November, 1974, with the construction of 6 subsurface stratigraphic cross sections (4 east-west and 2 north-south ties) consisting of density logs of all 25 tract core holes. Standard scale logs of 1"-20' (vertical) were photographically reduced to a more convenient 1"-50' scale for these sections.

Amoco EDP (Electronic Data Processing) generated new histogram logs for all 12 pre-sale tract core holes plotting shale GPT grade versus depth at a log vertical scale of 1"-20'. These logs portray grades based on both lab-assay data of recovered core and density log estimates of missing core intervals. As G-S core hole Fischer assays were received from Core Lab, Rio Blanco manually constructed similar scale histogram logs for these new holes. After additional information was posted to these logs by Amuedo and Ivey (discussed below), they were photographically reduced to the more convenient 1"-50' vertical scale and

a second set of 6 subsurface stratigraphic cross sections constructed, identical in lay-out and vertical scale to the previously constructed 6 density log sections.

These two sets of cross sections, designed to complement each other, provided the base control necessary to develop a detailed subsurface correlation network across Tract C-a. In addition, they provided a convenient means to visually display the stratigraphic positions of other significant data as discussed below.

Amuedo and Ivey were assigned the task of developing the Tract C-a subsurface correlation network following guidelines established by Rio Blanco. Rio Blanco's files containing data previously compiled on the 12 pre-sale core holes together with all new data in the 13 G-S core holes were furnished to A&I who:

- Established over 120 correlative log "picks" on the density log cross sections which are stratigraphically persistent throughout the tract's 25 core holes in the oil shale-bearing interval defined at its base by the Orange marker and extending upward to about 150' above the A-groove. Average correlation frequency within this 1200-1300' thick interval is about one every 10' of logged hole. Both gamma ray and density log responses were used to establish the correlations (A&I, 1975-C, p. 4). The gamma ray response reflects variations in the rock's natural radioactivity. The density response reflects variations in its oil content but must be used with caution since it is highly sensitive to hole gauge and rock vugularity.
- Correlated the 120+ log "picks" established on the density log cross sections to their stratigraphic equivalents on the histogram cross sections by matching density log responses to corresponding histogram log peaks and troughs (discrete assay increments of high and low grades). Slight adjustments were made as required uphole or downhole to compensate for suspected out-of-place core. However, stratigraphic continuity was maintained with no correlations allowed to cross bedding planes.

- Established a rich-lean oil shale zonation based on the density and histogram log cross sections placing as much 17+ GPT shale as possible into the rich zones and still maintain stratigraphic continuity. Zones were designated (named) using established USGS nomenclature (Cashion and Donnell, 1972) and expanded stratigraphically above and below the oil shale interval discussed in that reference. A total of 19 zones, 9 rich and 10 lean, together with over 100 "subzones" were defined in the tract's 1200-1300' thick oil shale-bearing interval discussed above.
- Posted the established tract correlation network on the two sets of tract stratigraphic cross sections showing:
  - Zonal correlations on the grade histogram log sections.
  - Both zonal and "subzonal" correlations on the density log sections.
- Prepared for computer input purposes a data sheet for each tract core hole listing all zonal and "subzonal" correlations established together with their respective density and histogram log depths.

A&I were assigned additional tasks to be performed concurrent with the development of the Tract C-a subsurface correlation network. These tasks involved the compilation of significant subsurface data and the posting of this data to appropriate core hole logs. At this point in time, the correlation network's set of 6 reduced 1"-50' vertical scale density log cross sections was already constructed. However, the grade histogram logs of the tract core holes were still at the standard vertical scale of 1"-20' with Core Lab Fischer assays in a few of the G-S core holes yet forthcoming. After all assays were received and the histograms plotted, A&I posted additional data to these larger scale histogram logs which were subsequently reduced to the more convenient 1"-50' vertical scale for construction of the correlation network's second set of 6 cross sections. At Rio Blanco's direction, A&I:

- Estimated GPT oil grades from density logs of all missing (lost) and "unreleased" core intervals, the latter retained for rock mechanics tests. Grade estimates were made in all G-S core holes except G-S 13 whose entire core is held for rock mechanics tests. Estimates were

listed numerically on Core Lab assay sheets for Amoco EDP computer input and posted on appropriate 1"-20' vertical scale core hole histogram logs (later reduced for cross section construction).

- Reviewed lithologic core descriptions in all 25 tract core holes to:
  - Locate evidence of suspected faulting in the subsurface.
  - Define the base of the leached zone.
  - Identify the mode of nahcolite occurrence (beds, stringers, nodules, etc.)
- Posted to the correlation network's 1"-50' vertical scale density log cross sections:
  - Evidence of suspected faulting in the subsurface, all tract core holes.
  - Base of the leached zone, all tract core holes.
- Posted to individual 1"-20' vertical scale grade histogram logs (later reduced for cross section construction):
  - Mode of nahcolite occurrence, all tract core holes.
  - Core Lab quantitative analyses of acid extractable alumina in spent shale, 8 G-S core holes.
  - Core Lab quantitative analyses of nahcolite, all G-S core holes where present (except G-S 13).
  - USBM X-ray diffraction analyses of dawsonite and nahcolite, 2 Cameron core holes, Nos. 702 and 707.

As A&I's work progressed both on the tract's subsurface stratigraphic correlation network together with the compilation and posting of additional data to appropriate core hole logs, results were periodically reviewed with Rio Blanco to resolve any problem areas. The network and both its cross sectional displays (6 density log sections and 6 grade histogram log sections) were finalized and approved by Rio Blanco on March 5, 1975. A brief report summarizing A&I's work was completed on April 21, 1975.

Rio Blanco constructed trace element histogram logs of the 8 G-S core holes which were analyzed by Core Laboratories, Inc., for concentrations of antimony, arsenic, boron, cadmium, fluoride, mercury and selenium in fresh shale, spent shale and fresh overburden rocks. Each log portrays in bar graph and numeric

form the stratigraphic position of each interval analyzed and the analysis results in parts per million for each of the 8 core holes (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15). The data were first posted to standard 1"-20' vertical scale logs and later reduced to the more convenient 1"-50' scale matching the log scale of the tract correlation network's cross sections. Amuedo and Ivey finalized each reduced log with the posting of the network's 19 rich-lean zonal boundaries in March, 1975.

2. Resource - Preliminary Tract C-a resource compilation of oil shale, nahcolite and extractable alumina in spent shale progressed as various data were received. Early in the G-S core hole program, it became apparent that nahcolite is not a significant tract resource because of its relatively limited occurrence.

Detailed tract oil shale and extractable alumina resource compilation was initiated in early March, 1975. By necessity, this detailed compilation was preceded by the completion of:

- All Fischer assaying of "released" core and extractable alumina analyses of composite spent shale samples by Core Laboratories, Inc.
- All grade estimates from density logs of missing and "unreleased" core intervals in 12 of 13 G-S core holes by Amuedo and Ivey (core hole G-S 13 retained in its entirely for rock mechanics tests).
- The tract correlation network by A&I and its approval by Rio Blanco.
- Input and edit-check of all oil shale grade data, both lab-assays and density log estimates of 12 of 13 G-S core holes by Amoco EDP.

Amoco EDP data banks previously contained oil shale grade data, both lab-assays and density log estimates of missing core, in the 12 pre-sale tract core holes (3 Amoco, 6 Cameron and 3 TOSCO). With the addition of equivalent information in 12 of 13 G-S core holes, their data banks contained oil shale resource data in 24 of 25 Tract C-a core holes.

Amoco EDP generated a computer tape duplicating the above shale resource data in the 24 tract core holes. This tape and all other geologic data compiled by

Rio Blanco were forwarded to Morrison-Knudsen Company, Inc., the major mining contractor, for use in their various investigations. M-K's computer application of the data included the construction of:

- The "prime mineral inventory" which defines the tract's oil shale resource adjusted to its present-day structural configuration. Computer input included core hole GPT grade data, the A&I stratigraphic correlation network and the RBOSP middle A-groove structure map.
- The "working mineral model" which provides output from the "prime mineral inventory" in a form suitable for open pit and underground mining evaluations. In open pit evaluations, selected horizontal "slices" 30, 40 and 50' thick can be made to define the resource in 100' by 100' squares throughout the tract. In underground mine evaluations, selected intervals between any two stratigraphic markers and 30, 60 and 80' thick intervals controlled at their tops by a stratigraphic marker can be made to define the resource in 100' by 100' squares throughout the tract.

Amoco EDP computed average GPT oil grades and thicknesses in each of the 24 assayed tract core holes for all 19 oil shale zones defined by the Tract C-a correlation network. Equivalent computer output from M-K was checked against Amoco's and found to be in perfect agreement. Amoco EDP also computed average grades and thicknesses for each tract core hole's main oil shale interval (middle A-groove to Blue marker) for tie to off-tract regional control. Rio Blanco then constructed hand-contoured isograde-isopach maps of the tract's 19 zones and main oil shale interval using reduced 1"-1000' horizontal scale Bovay topographic base maps. All 20 isograde-isopach maps were completed by the middle of June, 1975. These maps portray in-place oil shale resource characteristics across the tract.

As stated previously (item 3.1.F.2) the intervals in 8 G-S core holes selected by Rio Blanco for acid extractable alumina quantitative analysis of composite spent shale samples were based mainly on rich and lean oil shale zonation as evidenced by density log response. These composite samples were prepared by Core Lab, Rifle, concurrent with their Fischer assay program and analyzed by

Core Lab, Casper, well in advance of the tract correlation network's completion. Rio Blanco adjusted the analysis data to each of the network's 19 oil shale zones by standard weighting methods (multiplying each analysis increment thickness within a zone by its weight percent alumina, summing the products and dividing the sum by the zonal thickness to obtain the zone's average weight percent alumina). Total tonnage of extractable alumina in spent shale was then calculated for each of the 19 zones. Compilation of data in table form was completed in July, 1975.

3. Structural - Rio Blanco initiated the detailed structural compilation within Trace C-a and the immediate surrounding area with the selection of the middle A-groove horizon as the key structural marker for the tract. This electric log marker is regionally persistent throughout the Piceance Creek basin, easily identifiable without the benefit of Fischer assays and stratigraphically located near the top of the Mahogany zone, the uppermost rich zone within the Parachute Creek Member's main oil shale interval. Selection of this electric log marker was made at the very beginning of the G-S core hole program to monitor tract subsurface structure as evidenced by the new G-S core holes. The structure map maintained during the course of the drilling program was considered the "preliminary" tract structure map.

The structural compilation proceeded in a sequential manner incorporating additional control as it was obtained. Rio Blanco furnished Trollinger Geological Associates, Inc., with middle A-groove datums in on-tract core holes and in available off-tract core holes and conventionally drilled wells. TGA incorporated this subsurface structural control into their photogeologic interpretation of the tract and its immediate vicinity by form-line contouring structure at this horizon. TGA's final map therefore composited both subsurface and photogeologic control. At this point, the TGA map was considered the "second phase" tract structure map.

Amuedo and Ivey's surface geologic mapping followed using the TGA map for base control. A&I's surface mapping was added and the data lowered to the middle A-groove horizon by means of isopachs. Their final map, therefore, composited subsurface, photogeologic and surface geologic mapping control. At this point, the A&I map was considered the "third phase" tract structure map.

In the course of their respective structural investigations, both TGA and A&I were encouraged to make their own evaluations of the available data and present the structural interpretations each considered to be most likely. As is commonly the case in most structural evaluations, multiple interpretations of the same data were possible in certain parts of Tract C-a, particularly where associated with faulting. Rio Blanco reviewed all structural data compiled and where multiple interpretations were found possible, selected the one believed most probable. Considering the vast amount of structural data compiled on Tract C-a, most interpretations made by TGA, A&I and Rio Blanco are either in full or very close agreement. Significant variations in interpretation are relatively limited. Rio Blanco's middle A-groove structure map, submitted in this report, is the "fourth phase" tract structure map. It portrays Rio Blanco's interpretations in those areas where the previously discussed multiple interpretations were found possible.

As stated previously, most if not all the tract's major structural characteristics have been defined by compositing photogeologic, surface geologic and subsurface geologic mapping within the tract compiled to this data. Additional surface geologic mapping within the tract should not result in a major revision of its middle A-groove structure as currently known, but only further refine it. However, this does not preclude the need for periodic update of the tract's structure as additional subsurface control is obtained by supplemental core drilling, detailed review of the PGC seismic, or tract development (open pit and/or underground mining).

It should be pointed out that the Rio Blanco middle A-groove structure map for Tract C-a is identified as "Geologic Revision 1". It includes additional data obtained and evaluated subsequent to the structure map forwarded to the AOSS in RBOSP Progress Report No. 2 (Feb., 1975). Further revisions will be made as required if additional structural control is obtained which significantly changes the structure portrayed.

Finally, Amuedo and Ivey compiled joint-fracture orientation data from Birdwell seisviewer logs run in 8 G-S core holes (G-S 2-3, 7, 9, 10, 11, 12, 14 and 15)

and 4 deep conventionally drilled holes used for hydrologic testing (D-16, 17, 18 and 19). The 4 D-holes twin core holes G-S 12, CE 701, CE 702 and CE 705-A, respectively. These logs provide a continuous acoustic picture of the borehole wall oriented to magnetic north. A&I completed their investigations in April, 1975, and this data was forwarded to Morrison-Knudsen for use in their mining studies.

3.2 STRATIGRAPHY

A. General Information - Tertiary sedimentation in the tri-state area of SW Wyoming, NE Utah and NW Colorado was controlled by the geomorphic features produced by the Laramide orogeny. This series of major tectonic events occurred during late Cretaceous-early Tertiary time and formed large highland source areas from which Tertiary sediments were derived and subsequently deposited in the adjacent intermountain basins.

Tertiary environments of deposition varied considerably from basin peripheries toward their depositional centers resulting in the highly diversified rock types and facies changes so characteristic of continental sedimentation. Sediments deposited along basin edges nearest their source areas were characteristically more clastic than their more basinward stratigraphic equivalents. Pulsating uplift of the surrounding highlands (and/or corresponding subsidence of the basins), cyclic abundance of plant and animal life available to contribute organic material to the sediments, fluctuating lake shorelines, water depth and water chemistry (fresh, brackish, saline) were all important contributing factors in the type of sediments deposited. Roehler (1974, p. 57-64) identified ten environments of deposition in the Eocene rocks of the tri-state area ranging from mountain front or pediment to lacustrine evaporite. Geochemical conditions necessary for oil shale deposition were first postulated by Bradley (1929) and more recently by Smith (1969, p. 185-190; 1974, p. 71-79).

The oil shale-bearing Tertiary Green River Formation was deposited in two large Eocene lakes occupying two vast intermountain basins, one centered in SW Wyoming and the other in NE Utah and NW Colorado. Lake Gosiute occupied the greater

Green River basin of SW Wyoming, a portion of which extended southeastward into the Sand Wash basin of NW Colorado. Lake Uinta occupied the Uinta basin of NE Utah and the Piceance Creek basin of NW Colorado (Bradley, 1929, p. 88). The intervening present-day Douglas Creek arch was innundated by Lake Uinta (Donnell, 1961, p. 862) and was probably a gentle low relief sub-lake high. This probability is supported by thinning of Eocene sediments over the arch (Cashion and Donnell, 1972; Newman, 1974, p. 47-55).

Oil shale has been defined by various authors in different ways. The term is actually a lithologic misnomer because the rock is not shale nor does it contain oil in the conventional sense. Most oil shale is dolomitic marlstone (argillaceous limestone) containing variable amounts of organic matter derived chiefly from algae, aquatic organisms, waxy spores and pollen grains. This organic matter is only slightly soluble in ordinary petroleum solvents, but a large part can be converted to synthetic oil by destructive distillation. Standards have not been set for the minimum amount of extractable oil necessary to qualify the rock as oil shale. Therefore, the term is used more qualitatively than quantitatively (Brobst and Tucker, 1973, p. 3&4).

B. Regional - This discussion will be confined to the stratigraphy of the Piceance Creek basin in which Tract C-a is located and deal only with those intervals pertinent to the tract's development, namely, the oil shale-bearing Green River Formation and the overlying Uinta Formation.

Figure 3-3-3 is an updated generalized stratigraphic column of Eocene rocks in the Piceance Creek basin. No attempt is made to maintain vertical scale representative of individual unit thicknesses. It is designed to portray the relative stratigraphic positions of the major Eocene units discussed below. Also shown are the stratigraphic positions of the main oil shale interval of the lower Parachute Creek Member, the oil shale interval within Tract C-a and several key stratigraphic markers (both lithologic and geophysical log) which will be discussed in detail in the next item of this report.

There is a great amount of literature on the Tertiary stratigraphy of the Piceance Creek basin beginning principally with the classic work of Bradley

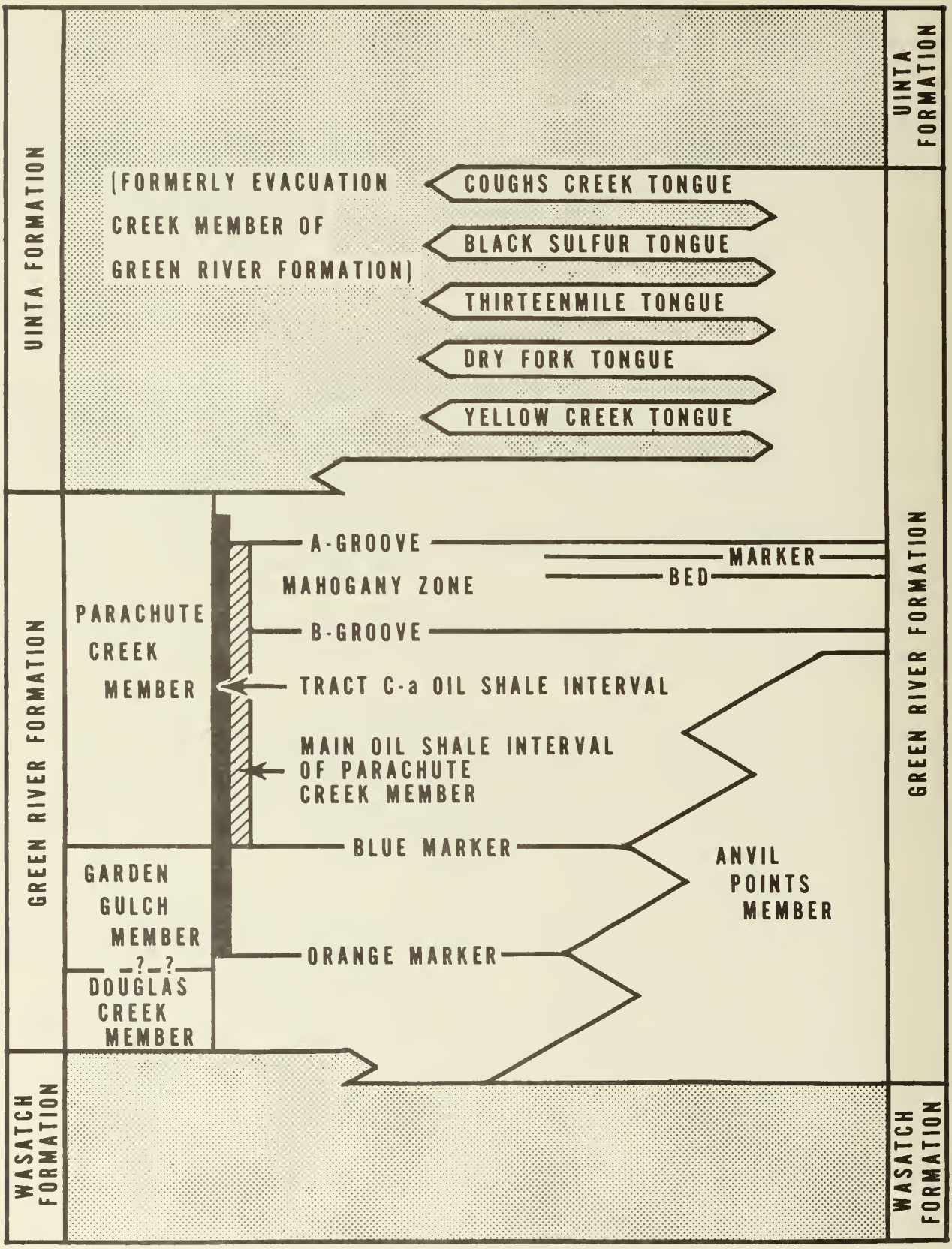


Figure 3-3-3

GENERALIZED STRATIGRAPHIC COLUMN OF TERTIARY EOCENE SERIES, PICEANCE CREEK BASIN

(1929, 1931) and continuing to the present time. Bradley divided the Green River Formation into four members, named in ascending order, the Douglas Creek, Garden Gulch, Parachute Creek and Evacuation Creek Members, with the youngest member forming most of the surface bedrock over the basin. Donnell (1961, p. 851) added a fifth member, the Anvil Points, along the eastern margin of the basin. It is a near-shore clastic facies laterally equivalent to the more basinward Douglas Creek, Garden Gulch and lower part of the Parachute Creek Members.

Bradley's nomenclature remained unchanged for over 40 years until the Evacuation Creek Member was determined to be stratigraphically equivalent to the lower part of the Uinta Formation in the Uinta basin of Utah (Cashion and Donnell, 1974). With the revised correlation, the Green River Formation is now composed of three main members (and Donnell's Anvil Points Member) and the overlying Uinta Formation comprises most of the surface bedrock of the Piceance Creek basin.

The lower two members of the Green River Formation, the Douglas Creek and overlying Garden Gulch, are undifferentiated in this report because there is some disagreement as to where the boundary of the two is located in the basin's subsurface. Operators of the Rio Blanco Gas Unit, southeast of Tract C-a, use the base of the Orange marker as the boundary (Chancellor, et al, 1974, p. 227). However, Roehler (1974, p. 60) states none of the rocks mapped as Garden Gulch in most parts of the basin are equivalent to Bradley's type section on the outcrop.

The lacustrine Douglas Creek-Garden Gulch Members (undifferentiated) consist mainly of interbedded gray shale, mudstone and sandstone in its lower part and gray to black oil shale in its upper part. The unit intertongues with the underlying fluvial Wasatch Formation. This intertonguing represents the initial phases of Lake Uinta and the transition from a fluvial to a lacustrine environment of deposition. Its contact with the overlying Parachute Creek Member is placed at the Blue marker in the basin's subsurface.

The lacustrine Parachute Creek Member contains the major portion of the basin's oil shale resources. It consists mainly of tan, brown and black oil shale interbedded with thin tuffs (volcanic ash beds) in its lower part and barren marlstone and siltstone in its upper part. Saline minerals are also present in its lower part (nahcolite, dawsonite and halite) whose concentrations increase towards the geochemical depositional center of the basin. The member's contact with the overlying Uinta Formation is generally both gradational (transitional) and intertonguing.

The Uinta Formation was deposited during the waning phases of Lake Uinta and its sediments reflect a transition from a lacustrine to a fluvial environment of deposition (Cashion and Donnell, 1974, p. G3, Duncan, et al., 1974, p. F3). It consists mainly of light brown to brown lenticular sandstone and siltstone. Several of the sandstones are thick, massive and medium to coarse-grained (Donnell, 1961, p. 857). Evidence of local channeling of these sandstones into underlying sediments has recently been defined (O'Sullivan, 1975, p. G4). Interbedded with these dominantly clastic sediments are lesser amounts of lacustrine light-gray marlstone. Five of these marlstone units have been recently mapped within the Uinta Formation which exhibit considerable areal persistence and merge laterally with the underlying Parachute Creek Member of the Green River Formation. These units have been designated tongues of the Green River Formation. In ascending order, they are named, Yellow Creek, Dry Fork, Thirteenmile, Black Sulfur and Coughs Creek Tongues (Duncan, et al, 1974; O'Sullivan, 1975).

C. Tract C-a

1. Key Stratigraphic Markers - Figure 3-3-4 is a 3-core hole SW-NE cross section across Tract C-a oriented normal to isopach or depositional strike of the Parachute Creek Member's main oil shale interval (defined below). It is designed to conveniently portray the tract's major stratigraphic characteristics. The section shows the stratigraphic positions of four key electric log markers and two key lithologic markers which are persistent throughout most of the Piceance Creek basin and are extremely useful in subsurface correlations, both locally and regionally. The electric log markers are particularly useful in

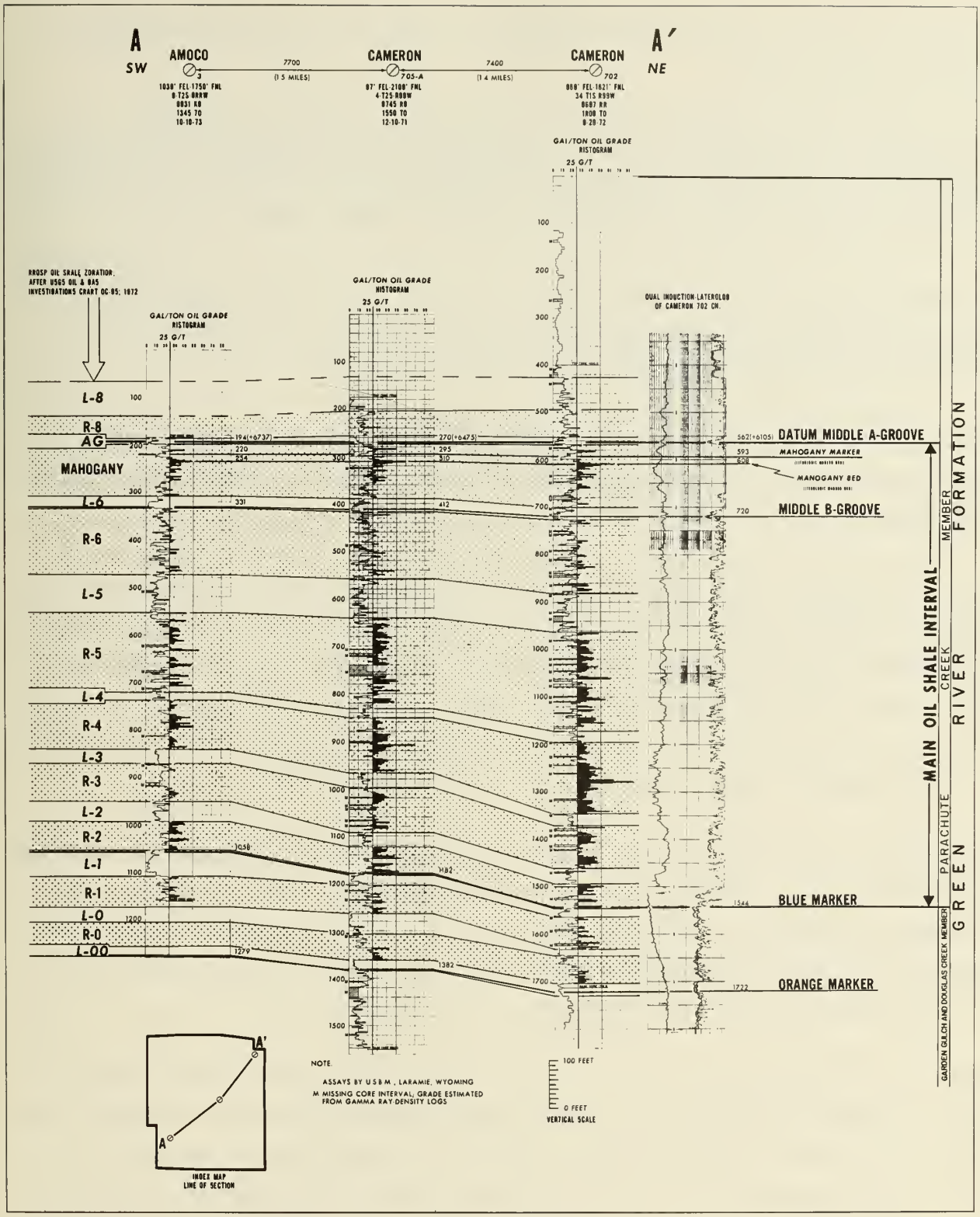


Figure 3-3-4

SW-NE 3-CORE HOLE HISTOGRAM CROSS SECTION, TRACT C-a

that they are easily recognizable without the benefit of Fischer assay data or lithologic descriptions.

The four electric log markers are, in stratigraphically ascending order, the Orange marker, Blue marker, B-groove and A-groove. All are associated with low resistivity intervals which reflect low grade oil shale zones.

The Orange marker forms the base of a low resistivity interval and defines the lower stratigraphic limit of the richer oil shale zones in the upper part of the Douglas Creek-Garden Gulch Members (undifferentiated).

The Blue marker forms the top of a low resistivity interval and defines the contact of the Douglas Creek-Garden Gulch Members with the overlying Parachute Creek Member.

The A and B-grooves are two low resistivity units which define the top and bottom of the Mahogany zone, respectively. The tops or bases of these grooves have commonly been used in subsurface mapping throughout the basin. However, their deepest inflections on resistivity logs (middle A-groove, middle B-groove) are more consistent regional "log picks", particularly where the resistivity log deflections are gradational and not sharply defined.

The A-groove and Blue marker are very important key markers because they define the top and bottom, respectively, of the main oil shale interval of the lower Parachute Creek Member. Although some rich oil shales occur immediately above and below this interval, the thickest and richest oil shale zones are within the stratigraphic section defined by these two key markers.

Within the Mahogany zone are two important lithologic markers in its upper part. The Mahogany marker is an analcimized tuff or volcanic ash bed generally 2 to 6" thick about 25 to 30' below the middle of the A-groove. About 15' below the Mahogany marker is a 2 to 4' thick interval of very high grade dark brown to black oil shale called the Mahogany bed. It stands out distinctly on oil shale grade histogram logs.

2. Lithology - Several of the key stratigraphic markers described in the previous item provide convenient boundaries which segregate major lithologic units within Tract C-a. The following is a brief description of these units as summarized from core description logs and surface stratigraphic data compiled by A&I (1975-B).

The uppermost part of the Douglas Creek-Garden Gulch Members of Figure 3-3-3 and Figure 3-3-4 (Orange marker to Blue marker) consists mainly of light gray to brownish gray oil shale with lesser amounts of gray shaley siltstone. Illite clay is reported to comprise the major portion, 60-70%, of the shale's mineral constituents (Robb and Smith, 1974, p. 94). As such, the interval may be more aptly described as organic-rich clay shale rather than oil shale defined as organic-rich dolomitic marlstone. The interval ranges in thickness from about 180 to 240' increasing across the tract generally to the southwest. This thickening towards the Douglas Creek arch, the basin's margin, reflects the inclusion of additional clastics (Trudell, et al., 1974, p. 68) from a probable source area in that direction.

The overlying main oil shale interval (Blue marker to A-groove) of the lower Parachute Creek Member consists mainly of dolomitic marlstone with variable amounts of organic matter (oil shale). Numerous thin tuff beds are interbedded with the oil shale. Illite is reported to comprise less than 20% of the oil shale's mineral constituents (Trudell, et al., 1974, p. 68). Higher grade shales are generally brown, dark brown or black. Lower grade shales tend to be lighter in color, commonly gray, tan or light brown. The interval ranges in thickness from about 860 to 980' increasing across the tract basinward to the northeast. Dawsonite and minor amounts of nahcolite are present in this interval, both of which will be discussed in a later item of this report. Vugs resulting from the dissolution of nahcolite are scattered throughout the interval and are particularly concentrated in one zone where the term "Swiss cheese" is most descriptive.

The overlying upper part of the Parachute Creek Member ranges in thickness from about 360 to 580' increasing basinward across the tract to the northeast. Its

lowermost 110 to 140' is mainly light gray to medium brown marlstone (oil shale) grading upward into light gray barren marlstone interbedded with gray siltstone and fine-grained sandstone. Outcrops of this unit's uppermost beds form the light gray canyon walls in the tract's major drainages.

The overlying Uinta Formation covers most of the tract's surface. It consists mainly of brown to light brown fine-grained massive sandstones with lesser amounts of siltstone. The formation's contact with the underlying Parachute Creek Member is transitional and is placed at the major color change between dominantly light gray sediments below and dominantly brown sediments above. Its thickness ranges over the tract from 0 to 350'.

3. Correlation Network - The subsurface stratigraphic correlation network established within Tract C-a is based on a set of 6 cross sections across the tract (4 east-west and 2 north-south ties) consisting of gamma ray-density logs of all 25 tract core holes. Key starting points for the network's construction were the four key regionally persistent electric log markers discussed previously, namely, the A and B-grooves and the Blue and Orange markers. The mechanics of the network's development were discussed under Geologic Evaluation, Stratigraphic.

Each density log cross section shows all 124 correlations established in the 1200 to 1300' thick interval defined at its base by the Orange marker and extending upward to about 150' above the A-groove. Correlation frequency averages about one every 10' of logged hole (A&I, 1975-C, p. 4). These cross sections, supplemented with equivalent oil grade histogram cross sections, provide the stratigraphic integrity throughout the tract necessary to precisely define its oil shale resources.

4. Oil Shale Zonation - The oil shale zonation established within Tract C-a is shown on Figure 3-3-4, the 3-core hole cross section across the tract. The zonation is based on that established by Cashion and Donnell (1972), discussed below, which zoned the main oil shale interval of the Parachute Creek Member bounded at its top by the A-groove and at its base by the Blue marker. Rio Blanco's zonation expands their zonation above and below the main oil shale interval resulting in 19 zones, 9 rich and 10 lean. These zones are designated

L-00 through L-8 in stratigraphically ascending order. The Mahogany and A-groove (AG) zonal nomenclature is retained because of their well established usage. They would be equivalent to an R-7 and L-7 zone, respectively, if the letter-number designations were used since they lie stratigraphically between the underlying R-6 and L-6 zones and the overlying R-8 and L-8 zones.

Two basic parameters control the zonation established within Tract C-a. First, as much 17+ GPT shale* as possible was placed into the richer zones. Second, stratigraphic continuity was maintained based on equivalent correlations on both the density log and histogram cross section sets of the tract correlation network.

Alternating rich and relatively lean oil shale zones in the Green River Formation are not unique to Tract C-a. They reflect widespread cyclic changes in lacustrine environments of deposition whose regional persistence has long been recognized. Bradley (1931) mapped the Mahogany ledge (zone in subsurface) and his "upper and lower oil shale groups" throughout parts of the outcrop area in both the Piceance Creek and Uinta basins. Trudell, Beard and Smith (1970) constructed a series of cross sections throughout the Piceance Creek basin relating the stratigraphic positions of both lithologic and geophysical log markers to rich and lean oil shale zones. Cashion and Donnell (1972) published a Utah to Colorado correlation chart which divided the main oil shale interval of the Parachute Creek Member into several rich shale zones separated by lean zones and designated the rich zones R-2 through R-6 and Mahogany in ascending stratigraphic order. Brobst and Tucker (1973, p. 7) later applied the Cashion and Donnell zonation to the "pipeline section" outcrop on Cathedral Bluffs about five miles southwest of Tract C-a and added letter "L" designations to the lean shale zones.

Any attempt to explain the alternating rich and lean oil shale zones, either within Tract C-a or regionally, first requires a brief review of rich versus

*During the initial phases of tract zonation, the density log response of 2.218 grams/cc was found convenient to segregate relatively rich zones from relatively lean zones. Subsequent assay results indicated this log response was equivalent to approximately 17 GPT. Although this grade is not the actual cutoff grade, it is reasonably close, and its continued use for zonation purposes (rich versus lean) appears warranted.

lean oil shale production. In its most basic terms, rich oil shale production required two essential conditions:

- An abundant supply of organic matter derived from the remains of plentiful aquatic and near-shore terrestrial plant and animal life, particularly aquatic plant life.
- An environment of deposition conducive to the preservation of that organic matter.

When both conditions were optimum, rich oil shale was produced. When either one or both conditions were of lesser quality, relatively leaner oil shale was produced.

Bradley (1929, p. 101) first recognized the first condition on a seasonal organic growth basis and termed the results "varves" which are cyclic pairs of minute laminations, one darker and richer than the other due to the inclusion of relatively more organic matter. Both Bradley (1929, p. 103) and more recently Smith (1969, p. 187; 1974, p. 74) proposed the existence of a thermally and chemically stratified Lake Uinta consisting of two non-mixing layers to explain the second condition. The upper layer was an oxidizing environment, warm and fresh enough to support prolific aquatic life. The lower layer was a cooler, fairly stagnant reducing environment favorable to the preservation of organic remains settling to the lake floor.

The concept of a stratified lake consisting of two non-mixing layers requires a relatively deep water-low energy environment. Waves and currents in the upper layer were moderate while currents in the lower layer below wave base were relatively slow. Bradley (1929, p. 103) proposed a water depth of 75 to 100' to provide the quiescent waters needed for a stratified Lake Uinta but also cited the present-day formation and preservation of varved sediments in McKay Lake, Ottawa, at depths of only 32'. Later, Bradley (1966, p. 1333-1338) discovered organic remains similar to those of the Green River Formation being deposited at the bottoms of four present-day lakes, two in Florida and two in East Africa, at depths of only 2 to 30'. In addition, the organic material did not decay in these four lakes even in an oxidizing environment.

These findings may cause some argument as to the need for lake stratification with a lower reducing layer required to preserve organic matter for oil shale production. However, the formation of oil shale's characteristic long-range correlative varves and their subsequent preservation strongly support a persistent and quiescent lake bottom, below wave base and with slow lake bottom currents, precluding depths of just a few feet. With depths of just a few feet, periodic storm-induced wave and current action would tend to destroy the fragile varved sediments. Bradley's originally proposed depth of 75 to 100' for Lake Uinta still appears valid although a depth as shallow as about 30' is not unreasonable as evidenced by the present-day varved sediments at Lake McKay, Ottawa.

In summary of the above review of rich versus lean oil shale production:

- Rich shale was produced when both essential conditions were optimum; an abundant supply of organic matter coupled with an environment of deposition conducive for its preservation.
- Lean shale was produced when either one or both essential conditions were less than optimum.
- Lake depths in the 75 to 100' range, but possibly as shallow as only about 30', were sufficient to provide the quiescent water needed for lake stratification into two non-mixing layers. The upper layer was a moderate energy environment, oxidizing, and capable of supporting prolific aquatic life. The bottom layer was a low energy environment, reducing, and favorable for the preservation of organic matter. More shallow lake depths resulted in a bottom layer of relatively higher energy environment, less reducing, and therefore less favorable for the preservation of organic matter.
- Alternating rich and lean oil shale zones are analogous to Bradley's "varves". Both reflect basinwide cyclic production of rich and lean shale. While "varves" were seasonal in duration of deposition (annual), the thicker alternating rich and lean zones may be termed "mega-varves" representing deposition over considerably longer time-spans.

One important factor remains to be considered which significantly influenced oil shale deposition and the resultant alternating rich and lean zones within Tract C-a. That factor is the geographic location of the tract within the Piceance Creek basin.

Tract C-a is located on the west flank of the Piceance Creek basin about 15 miles east of the crest of the northerly trending Douglas Creek arch. During Lake Uinta time, the arch was a gentle low-relief sub-lake high, a "shoaling area", perhaps even slightly emergent at times, with lake waters more shallow on or near its crest than basinward down its flanks. Cyclic changes in lake level of just a few feet may have shifted favorable oil shale depositional conditions related to lake depth several miles depending on lake bottom slope. A lowering of the level, a lake regressive stage, shifted favorable depth conditions basinward to the northeast (tract lean zone deposition). A rise in the level, a lake transgressive stage, shifted favorable depth conditions outward to the southwest covering a more extensive area (tract rich zone deposition). Cyclic periods of abundant and less abundant aquatic life growth may have also contributed to the deposition of alternating rich and lean zones within the tract as well as regionally. The 3-core hole cross section of Figure 3-3-4 shows additional influence of the Douglas Creek arch on Tract C-a oil shale deposition. Zones L-0 through L-2 generally thicken southwestward across the tract towards the arch reflecting the inclusion of additional clastics derived from a source area in that direction. The overlying R-3 through L-8 zones generally thicken northeastward across the tract towards the basin's depocenter.

Finally, as shown in Figure 3-3-4 the main oil shale interval of the Parachute Creek Member contains most of the rich oil shale zones and stratigraphic sections above and below the main oil shale interval contain relatively lower grade oil shale zones. This "sandwich" relationship reflects cyclic gradational changes in environments of deposition associated with Lake Uinta, proceeding from relatively lean to relatively rich and back to relatively lean oil shale generation.

5. Accessory Minerals

a. Acid Extractable Alumina - Quantitative analyses of composite interval spent shale samples in eight G-S coreholes spaced across Tract C-a (G-S 1, 2-3, 4-5, 7, 9, 10, 11 and 15) indicate extractable alumina (Al_2O_3) is present in all 19 rich and lean zones as well as in the relatively low grade to barren oil shales overlying them. Two important questions need to be answered; first, what minerals are contributing to the extractable alumina; and second, what is the stratigraphic distribution of these minerals?

The main minerals contributing extractable alumina are dawsonite $!NaAl(OH)_2CO_31$, analcite ($NaAlSi_2O_6 \cdot H_2O$) or analcime ($NaAlSi_2O_3 \cdot H_2O$), and a third mineral initially termed gibbsite $!Al(OH)_31$ to account for "excess alumina" (Smith and Young, 1969, p. 2). This third mineral was later tentatively identified as nordstrandite (Smith, 1974, p. 74) with the same aluminum trihydroxide formula as gibbsite. Dawsonite and the "excess alumina" mineral nordstrandite always occur with each other (Smith, 1974, p. 74) and are most heavily concentrated in the lower part of the main oil shale interval of the Parachute Creek Member.

"Excess alumina" was also recognized by Desborough and Pitman (1974, p. 85) based on bulk chemical analyses of eight very rich oil shale samples from four Piceance Creek basin core holes. Four samples from the Mahogany bed and four samples from a rich bed in the R-4 zone were tested. After allocation of the Al_2O_3 obtained to K_2O required for K-feldspar ($KAlSi_3O_8$), and to Na_2O_3 required for albite ($NaAlSi_3O_8$), analcime and dawsonite, excess Al_2O_3 remained. The presence of an aluminum-rich compound containing no sodium or silicon was also verified by microprobe analysis of one shale sample which contained 5 weight percent of surplus alumina.

Dawsonite occurs as microscopic crystals finely disseminated throughout the oil shale and as thin laminations along bedding planes (Hite and Dyni, 1967, p. 29). Analcime commonly occurs as an alteration product in volcanic ash beds (tuffs) but also occurs disseminated in oil shale (Desborough and Pitman, 1974, p. 85). The "excess alumina" mineral nordstrandite probably occurs in a manner similar to dawsonite.

As was the case in oil shale deposition and zonation discussed previously, the geographic position of Tract C-a within the Piceance Creek basin is again a significant factor influencing the stratigraphic distribution of extractable alumina minerals within it. Stratigraphic occurrences of these minerals outside the tract must be brought into proper prospective with similar information compiled within the tract.

Within Tract C-a, USBM X-ray diffraction analyses of core samples in core holes CE 702 and CE 707 (Smith, 1974, unpublished) show dawsonite and therefore nordstrandite (after Smith, 1974, p. 74) occur in a stratigraphic interval from the upper part of the R-2 zone through the lower part of the R-5 zone. A minor amount is also present in the L-1 zone of core hole CE 707. In addition, USBM X-ray diffraction analyses of bulk or composite interval core samples in core hole G-S 15 (Smith, 1975, unpublished) show a stratigraphic distribution of dawsonite similar to that of core hole CE 707. In the most basinward core hole CE 702, located in the northeast corner of the tract, analcime occurs commingled with dawsonite in only one of 219 dawsonite-bearing core samples (0.5%). In the most westward core hole CE 707, nearer the basin margin, analcime is commingled with dawsonite in 25 of 174 dawsonite-bearing core samples (14%). In the intermediate core hole G-S 15, analcime is commingled with dawsonite in 2 of 10 dawsonite-bearing composite interval samples (20%). The concentration of dawsonite is highly variable ranging from a few to as high as 15 weight percent in individual beds. Analcime occurs stratigraphically above and below the dawsonite-bearing interval, generally in higher concentrations.

At the "pipeline outcrop section" on Cathedral Bluffs in Sec. 34, T. 2 S., R. 100 W. about 5 miles southwest of Tract C-a, Brobst and Tucker (1973) described and sampled a 909' thick interval from the base of the Parachute Creek Member to about 310' above the Mahogany ledge. This interval is stratigraphically equivalent to the tract's R-2 through L-8 zones and above. X-ray diffraction analysis of 70 samples from the outcrop section indicates only analcime-bearing oil shale is present. Dawsonite-bearing shales are completely absent.

At the other extreme, about 12 miles northeast and basinward of Tract C-a, Robb and Smith (1974, p. 91-100) present a core hole X-ray diffraction mineral profile showing very high dawsonite concentrations occurring in oil shales of the lower part of the Parachute Creek Member. The core hole is the USBM-AEC Colorado No. 1 located in Sec. 13, T. 1 N, R. 98 W. The profile covers a stratigraphic interval 2,060' thick from the upper part of the Garden Gulch-Douglas Creek Members to the top of the Mahogany zone, equivalent to the tract's L-00 through Mahogany zones. In the very rich dawsonite-bearing shales of the 853' thick unleached saline section, analcime is completely absent except in only 6 samples analyzed. In the overlying 480' thick leached saline section immediately below the Mahogany, lesser amounts of dawsonite occur together with analcime but their concentrations are generally in inverse proportions. In other words, the two minerals do not favor each other in common occurrence. Analcime occurs both stratigraphically above and below the dawsonite-bearing shale interval.

Brobst and Tucker (1973, p. 40-42) located dawsonite and analcime occurring together in scattered oil shales below the Mahogany ledge in R-5 and R-6 zone outcrops along the extreme northern margin of the basin. The outcrops are located along lower Piceance Creek road in Sec. 11, 14 and 15, T. 1 N., R 97 W. In a 45' thick section in the R-5 zone, X-ray diffraction analysis of 54 samples showed that dawsonite content varies inversely with analcime content. Later, Desborough and Pitman (1974, p. 84) extended dawsonite's occurrence stratigraphically even higher when its presence was defined in the Mahogany zone's richest oil shale unit, the Mahogany bed, in four widely spaced core holes in the Piceance Creek basin. Analcime was found in common occurrence with dawsonite in two of the four core holes (Desborough, Pitman and Huffman, 1974, p. 5). In comparison, dawsonite's highest stratigraphic occurrence within Tract C-a is in the R-5 zone.

Stratigraphic distribution of extractable alumina minerals within Tract C-a is a compromise between Brobst and Tucker's outcrop section on Cathedral Bluffs southwest of the tract and Robb and Smith's mineral profile in the USBM-AEC core hole northeast of the tract. The former consists of analcime-bearing oil

shale with no dawsonite. The latter consists of a prolific dawsonite-rich shale interval in the lower part of the Parachute Creek Member with strong dawsonite-analcime mineral segregation sandwiched between two analcime-bearing shale intervals. The highest stratigraphic occurrence of dawsonite within the tract is in the R-5 zone while the USBM-AEC core hole it is in the R-6 zone.

In summary, the main minerals contributing to acid extractable alumina within Tract C-a in zones R-2 through R-5 are dawsonite and the "excess alumina" mineral tentatively identified as nordstrandite. In zones stratigraphically above and below these zones, analcime is the main contributor. The thickest and richest dawsonite-nordstrandite deposits occur in the lower part of the Parachute Creek Member basinward to the northeast of Tract C-a. Dawsonite-nordstrandite content decreases to zero at the basin's west margin with analcime peripheral to dawsonite-nordstrandite in stratigraphically equivalent sections on the outcrop. Although dawsonite-nordstrandite and analcime do not generally favor each other in common occurrence, some stratigraphic intermixing is present increasing southwestward across the tract as evidenced in the CE 707 and G-S 15 core holes. The intermixing, or stratigraphic overlap, was probably caused by periodic lake level fluctuations and lateral variations in the lake's geochemistry. Beard, Tait and Smith (1974, p. 103) report the same mineral relationship on a basinwide basis for the lower part of the Parachute Creek Member.

Based on the above summary, zones of interest for potential commercial extraction of alumina (utilizing a caustic leach method) include only zones R-2 through R-5, which contain mainly dawsonite and nordstrandite with lesser amounts of analcime. The acid extractable alumina analyses performed in these zones reflect alumina contributed mainly from dawsonite and nordstrandite as evidenced by the USBM X-ray diffraction analyses in three on-tract coreholes. Results of the acid extractable alumina analyses are presented in the confidential volume.

b. Nahcolite - Only minor amounts of nahcolite ($NaHCO_3$) were encountered in the G-S core hole program on Tract C-a. In core hole G-S 2-3, it was found to be totally absent. Where nahcolite was defined in the core, quantitative

analyses were performed. These analyses are complete except in core hole G-S 13 whose entire recovered core is retained intact for rock mechanics tests. The lack of nahcolite analysis data in this core hole is insignificant because it penetrated only one occurrence of nahcolite, a 3 to 4" bed in the R-4 zone.

Within Tract C-a, very limited amounts of nahcolite occur as thin beds, stringers, nodules and coatings or small crystal growths on both vug walls and shale partings. The few scattered beds that are present are usually less than 1' thick with a maximum thickness of 2' occurring in the L-2 zone of core hole CE 702, the most basinward core hole located in the northeast corner of the tract. Its relative abundance increases northeastward across the tract.

Stratigraphically, nahcolite occurs within the tract as high as the R-8 zone in core hole G-S 9 to as low as the R-2 zone in core hole G-S 8. However, most occurrences are in the lowermost part of the main oil shale interval's R-3 through R-4 zones.

The present-day occurrence of nahcolite within the tract is controlled by two factors; first, its primary deposition; and second, the subsequent removal of this water-soluble mineral by ground water. As was the case in previous discussions on both oil shale zonation and extractable alumina within Tract C-a, the tract's geographic position within the Piceance Creek basin exerted a significant influence on nahcolite's primary deposition within it.

Tract C-a is located about 7 miles southwest and peripheral to the geochemical depocenter of nahcolite and associated halite (NaCl). In the vicinity of the eastern part of T. 1 S., R. 98 W., deposition of these two minerals was most extensive in the lower part of the Parachute Creek Member. At this locality, nahcolite beds up to 30' thick and halite interstratified with nahcolite and oil shale in zones up to 65' thick were deposited. One core hole penetrated about 910' of oil shale which averaged 28.4 weight percent nahcolite (Dyni, 1974, p. 111-122). Away from this saline depocenter, both minerals decrease in concentration and thickness toward the basin margins. Primary deposition of nahcolite within Tract C-a was limited to nodules and a few relatively thin beds and stringers. Halite never was deposited within the tract.

Subsequent removal of the water-soluble nahcolite by ground water leaching has reduced its original concentrations within the tract considerably. The base of the leached zone is consistently in the lower part of the R-3 zone in all tract core holes with the exception of G-S 7 where it is stratigraphically higher in the lower part of the R-4 zone. The base of the leached zone is defined as the stratigraphically lowermost evidence in each core hole of nahcolite post-depositional removal by ground water. It is usually placed immediately below the lowermost occurrence of vugs or solution cavities and is equivalent to the "dissolution surface" of Hite and Dyni (1967, p. 27) and Dyni (1974, p. 117). Its position need not follow stratigraphic boundaries because it is a post-depositional event controlled by ground water action. Below the base of the leached zone, nahcolite originally deposited is still present. Above it, much of the originally deposited nahcolite has been removed, some of which was redeposited on vug walls and shale partings. The base of the leached zone is not sharply defined in that empty vugs or solution cavities and collapse breccia are present stratigraphically below unleached nahcolite occurrences (Trudell, et. al., 1974, p. 69). Evidence of nahcolite's removal by dissolution is scattered throughout the leached zone in all core holes within Tract C-a but is most striking in the R-3 zone. This zone is extremely vugular throughout most of the tract and the term "Swiss cheese" has been appropriately used in describing its core. In the equivalent unleached R-3 zone of core hole G-S 7, the core contains many nahcolite nodules and stringers.

6. Trace Elements - In the same eight G-S core holes spaced across Tract C-a selected for extractable alumina analyses (G-S 1, 2-3, 4-5, 7, 9, 10, 11, and 15), quantitative trace element analyses were performed on both fresh and processed shale. In addition, analyses were performed on fresh overburden rocks containing little to no oil shale. The seven trace elements tested for are antimony, arsenic, boron, cadmium, fluoride, mercury and selenium.

To minimize sample handling and preparation, the composite intervals selected in each core hole for trace element analyses were the same as those selected for extractable alumina in processed shale. Since interval selection preceded the establishment of the final oil shale zonation within the tract, interval boundaries are generally close but not necessarily coincident with the zonal boundaries.

Table 3-3-4 summarizes the fresh shale, processed shale and overburden analyses compiled in the eight G-S core holes listing the ranges and arithmetic average concentrations of each trace element. Arithmetic averages were compared to averages weighted to composite interval analysis thicknesses in two G-S core holes and found to be virtually identical.

Also shown in Table 3-3-4 for direct comparison are similar data on fresh shale recently reported by Desborough, Pitman and Huffman of the USGS (1974, p. 9). Their data are based on analyses of ten oil shale samples. Six samples are from the Mahogany bed, the richest oil shale unit in the Mahogany zone, four from core holes in Colorado and two from core holes in Utah. Their other four samples are from a rich bed in the R-4 zone, all from core holes in Colorado.

Desborough, et al., also cite the following additional trace element analyses in their report (1974, p. 11-13):

- Antimony - Concentrations ranging from 1 to 6 ppm in fresh shale as determined in their work are 2 to 15 times higher than those of Cook (1973), who reported 0.39 ppm in processed shale from the Mahogany zone. This difference may indicate that antimony was volatilized during retorting of Cook's sample.
- Arsenic - Concentrations ranging from 25 to 75 ppm in fresh shale as determined in their work are 3 to 10 times higher than that reported by Cook (1973) in processed shale from the Mahogany zone. This difference suggests that arsenic resides principally in the volatile organic-rich fraction and is therefore mobilized during retorting. However, additional studies of raw and processed shale show that this is not the case as evidenced by analyses of TOSCO composite core samples.

  A composite sample representing about 50' of the Mahogany zone was provided by TOSCO. One fraction was retorted by conventional Fischer assay methods. The processed shale represented 83.7 weight percent of the fresh shale. Ten separate portions of both fresh and processed

Table 3-3-4

TRACE ELEMENT SUMMARY; FRESH & PROCESSED SHALE, OVERBURDEN

(Concentrations in parts per million)

Trace Element	USGS Report Fresh Shale		8 G-S Core Holes Fresh Shale		Processed Shale		Overburden	
	Range	Avg.(a)	Range	Avg.(b)	Range	Avg.(c)	Range	Avg.(d)
Antimony	1-6	2.4	0.2-1.7	0.6	0.1-1.2	0.4	0.2-0.8	0.4
Arsenic	25-75	39.5	0.9-15.7	7.1	1.0-12.4	5.2	3.8-12.6	8.1
Boron	30-300	95	14-516	150	0.5-278	108	19-226	113
Cadmium	0.6-1.2	0.8	1.4-4.0	2.6	1.3-3.9	2.6	0.8-2.9	1.5
Fluoride	700-2100	1290	75-1488	622	64-1217	475	131-1134	485
Mercury	0.07-2.9	0.48	0.13-3.6	0.76	0.01-3.04	0.47	0.06-1.91	0.50
Selenium	0.1-3.0	1.7	0.1-1.3	0.4	0.1-1.1	0.5	0.1-0.7	0.2

Arthmetic Averages
(a) Avg. of 8-10 samples
(b) Avg. of 209-210 samples
(c) Avg. of 209 samples
(d) Avg. of 21 samples

Note:

1. EPA-recommended trace element quantitative analysis techniques used in the G-S program are listed in Table 3-3-3.
2. For additional discussion of trace elements, see Section 6, Chapter 3.2.D; Processing, Phase I Processing Emissions and Control. Further investigations are in progress to estimate the disposition of trace elements throughout the retorting and upgrading steps.

shale, each weighing 0.5 to 0.75 grams, were analyzed for arsenic by a commercial laboratory. The results of 10 analyses (ppm) for both fresh and processed shale is shown below.

	Fresh Shale	Processed Shale
Mean	62.5	64.5
Standard deviation	7.5	4.4
Range	55-75	60-70

The above results indicate that about 85% of the arsenic remains in the processed shale and about 15% is apparently volatilized during retorting, when the processed shale concentration is converted to raw shale concentration using the ash value of 83.7 weight percent. However, the actual amount volatilized during retorting is uncertain due to limited analytical precision.

- Mercury: Concentrations ranging from 0.07 to 2.9 ppm in fresh shale are reported by Desborough, et al., in their work. J. R. Donnell and V. E. Shaw of the USGS reported a range of 0.1 to 1.0 ppm for 183 analyses of a continuous sequence of oil shale from 30' above the top of the Mahogany zone to 60' below the base of the Mahogany zone. Cadigan (1970) reported a median (half higher, half lower) of 0.1 ppm for 260 samples from the Uinta and Green River Formations.
- Selenium: Concentrations ranging from less than 0.1 to 3 ppm in fresh shale as determined in their work are 10 to 20 times greater than the value of 0.08 ppm in processed shale reported by Cook (1973). The selenium in Cook's sample is suspected of being lost during retorting.

At this point, it is unknown why some of the USGS and Rio Blanco trace element concentrations shown in Table 3-3-4 are not in better agreement. Analytical methods, laboratory procedures, sample intervals (composite versus specific core increments) and sample contamination are some of the factors considered. We have discussed this question with Core Laboratories, Inc., who performed the trace element analyses on the G-S core hole samples. They have reviewed their work and believe their data are reliable. Further, we have discussed this question with J. R. Donnell and V. E. Shaw of the USGS and are cooperating with them to resolve it by furnishing G-S core samples for USGS analysis.

Desborough, Pitman and Huffman (1974, p. 8-13) report some of the mineralogical residences of these seven trace elements as follows:

Trace Element	Mineral Residence
Antimony	(Unknown)
Arsenic	Pyrite
Boron	K-feldspar
Cadmium	Sphalerite or Wurtzite
Fluoride	Fluorite and Cryolite
Mercury	(Unknown)
Selenium	Sulfide minerals or iron selenide

Colorado School of Mines Research Institute (1975) conducted mineral residence analyses for these seven trace elements in fresh and processed shale composite samples from core holes G-S 2-3 and 7. Their work, utilizing X-ray diffraction and element partitioning techniques together with a comparison of the relative abundance of the trace elements with the relative abundance of identified minerals in the samples, indicates that with the exception of cadmium not occurring in quartz, the seven trace elements possibly occur by ionic substitution in many of the common minerals comprising oil shale; namely, quartz, dolomite, calcite, analcime, feldspar, illite, dawsonite and pyrite. In addition, comparison of analysis results between equivalent samples of fresh and processed shale indicates that only two of the trace elements, arsenic and selenium, are present in possibly significant quantities in kerogen, the organic fraction in oil shale. The other five are associated primarily with the mineral fraction and are retained in the shale after retorting.

7. Measurements of Methane and Hydrogen Sulfide Gas - Methane (CH_4) is the simplest and most common hydrocarbon compound generated by the decomposition of organic matter in the absence of oxygen. If the organic matter is sulfur-bearing, which it commonly is, hydrogen sulfide (H_2S) is also formed. In the case of oil shale, as well as coal and marine shales, both gases are commonly generated in the subsurface as a direct result of the sediment's partial distillation.

Both methane and hydrogen sulfide have been detected in the oil shale section within Tract C-a. The gases probably occur trapped in vugs and fractures as well as dissolved in the ground water. Hydrogen sulfide is very soluble in water while methane is slightly soluble.

- Methane - In all 13 G-S core holes, gas samples for methane quantitative analysis were collected generally when the A-groove, B-groove and total depth were reached. The three samples collected in core hole G-S 8 were lost, possibly during transit off tract; therefore, no analyses are available in this core hole.

  In the G-S core hole program, a total of 49 gas samples were analyzed, 36 of which either contained no methane or methane in quantities too small to measure (reported as "nil"). The remaining 13 samples contained methane ranging from less than 0.01 to 3.21 vol. % and averages 0.91 vol. %. Methane concentrations were consistently highest in samples collected at or near total depth when the entire oil shale section was exposed to the bore hole. These highest concentrations at total depth suggest a combination of several uphole shale intervals simultaneously contributing methane to the bore hole.

  Table 3-3-5 summarizes the 13 analyses of methane where this gas was present in measurable quantities. Also shown are the two analyses of ethane where this gas was detected.

  There is some question as to the reliability of the methane quantitative analysis results because of the sample-catching procedure used. Samples were collected in evacuated steel cylinders by tapping into the "blooey line", the pipe discharging the return air-mist drilling fluid. Any methane present was already diluted by the air-mist fluid. The 3.21 vol. % analyzed in the sample obtained at 1746' near total depth in core hole G-S 13 suggests a higher methane concentration may have been present in this hole which was diluted by the air-mist drilling fluid prior to sample capture.

  Another factor which may result in questionable quantitative methane data is the so-called "flash effect" which may be applicable to certain oil shale intervals. In the D-J basin of eastern Colorado, the Cretaceous Niobrara Formation contains marine shales which

Table 3-3-5

SUMMARY OF METHANE MEASUREMENTS, G-S CORE HOLE PROGRAM

Core Hole	Location of Measurements: Depth	Zone	Mole %[(a)] Methane (CH_4)	Mole % Ethane (C_2H_6)
G-S 1	1404 TD	-L-00	0.19	0.02
G-S 4-5	1663 TD	-L-00	1.39	N
G-S 6	636	MZ	0.03	N
	647	MZ	0.05	N
G-S 7	1200 TD	-L-00	0.23	N
G-S 9	955	R-5	< 0.01	N
G-S 10	1129	R-5	0.19	N
	1903 TD	-L-00	1.90	N
G-S 11	1886 TD	-L-00	0.32	N
G-S 12	1800 TD	-L-00	1.96	N
G-S 13	1746	-L-00	3.21	< 0.01
G-S 14	1794 TD	-L-00	1.21	N
G-S 15	1833 TD	-L-00	1.16	N

Note: -L-00 = below L-00 zone
N = None
(a) Equivalent to volumetric percent for an ideal gas. The difference between the two for methane at standard conditions is negligible.

release significant quantities of methane to the drilling fluid (mud) due essentially to the rotary cutting and grinding action of the drill bit. Mud-logging units commonly record high methane readings in the drilling mud while this formation is being penetrated. However, when these "gas shows" are drill-stem tested, usually little to no gas is recovered. Once the well has drilled through the Niobrara Formation toward deeper objective horizons, methane readings in the mud-logging units normally decrease rapidly and stabilize after the gas has left the mud stream while circulating through the mud pits.

- Hydrogen Sulfide - The distinct odor of hydrogen sulfide was noted in all but 4 of the 13 G-S core holes, namely, G-S 1, 7, 8 and 12. It is noteworthy that these four core holes are all located in the western half of the tract suggesting a general westward decrease in the presence of this gas. It was also reported in several of the pre-sale core holes as well. Its stratigraphic occurrence is erratic, ranging from as high as above the L-8 zone in core holes G-S 6 and 13 to as low as below the L-00 zone in G-S 14 and 15. Its noted presence at any given depth in a core hole does not necessarily mean its source is the shale interval at or near the depth at which it is reported. It may have entered the bore hole from any interval(s) above that depth.

  Late in the G-S drilling program, it was noted that the analyses of gas samples collected in cylinders off the "blooey lines" failed to disclose the presence of measurable quantities of hydrogen sulfide. Yet, its odor at times suggested concentrations may have been present in measurable quantities. The cylinders were examined for evidence of H_2S reaction with their inner metallic walls but none was found. Hydrogen sulfide monitors were installed on core holes G-S 11, 14 and 15 and on the four D-holes (deep hydrologic tests) twinning core holes G-S 12, CE 701, 702 and 705-A. Unfortunately, these monitors were prone to frequent breakdown. However, when operative, most hydrogen sulfide concentrations observed were less than 1 ppm (parts

per million). The maximum concentration recorded was 2.8 ppm at depth 958' in the R-4 zone in D-19 which twinned the CE 705-A core hole.

3.3 STRUCTURE

A. Regional - The Piceance Creek basin is a broad northwest-trending structural trough about 130 miles long and 60 miles wide (Murray and Haun, 1974, p. 36). These dimensions far exceed that part of the basin presently underlain by the Green River Formation which is an area approximately 60 by 40 miles. Considerable Green River sediments around the basin's periphery have subsequently been removed by erosion.

The basin is bounded on the north by the Axial Basin uplift (Axial Fold and Fault belt, an eastward extension of the Uinta Mountain uplift); on the east by the White River uplift whose west flank is the Grand Hogback monocline; on the southeast and south by the Elk and West Elk Mountains and Gunnison uplift; on the southwest by the Uncompahgre uplift; and on the west by the Douglas Creek arch which separates the Piceance Creek basin from the Uinta basin of Utah (Murray and Haun, p. 33).

The basin is asymetric with very gently dipping flanks on the south and west and more steeply dipping flanks on the north and east. Pre-Green River formations along the Grand Hogback on the basin's east side are locally vertical or even overturned. The structural axis of the basin is within 20 miles of its north and east margins (Donnell, 1961, p. 859).

Numerous gentle subparallel northwest-trending folds are present in the basin. The most prominent of these folds is Piceance Creek dome with structural closure of over 200' mapped at the surface (Donnell, 1961, p. 859). Faults are also present which generally trend in the same direction as the folds. Several pairs of these faults define graben (Donnell, 1961, Austin, 1971, Murray and Haun, 1974, p. 35). A graben is a crustal block between two faults, generally elogate compared to its width, that has been lowered or downthrown

relative to blocks on either side. The graben-bounding faults are generally steep, and in most cases, if not all, are either normal faults (gravity or tension) or are essentially vertical. In some cases, these faults have been described as steep reverse faults but the validity of these observations is questionable (Billings, 1942, p. 201). The graben-bounding faults commonly converge with depth because, by definition, their hanging walls are lowered relative to their footwalls.

B. Tract C-a - Tract structure as interpreted by RBOSP from photogeologic (TGA, 1974), surface geologic (A&I, 1975-B) and subsurface core hole and off-tract well control is shown on Figure 3-3-5. The datum mapped is the middle of the A-groove, the top of the Parachute Creek Member's main oil shale interval as portrayed on the cross section of Figure 3-3-4. Planes of all faults mapped at the surface are assumed to be essentially vertical in their subsurface projection.

1. Faults and Folds - Tract C-a is located on the west flank of the Piceance Creek basin about 5 miles east of Cathedral Bluffs. Beds within the tract strike generally to the north and dip basinward to the east and northeast at an average rate of 200 to 350' per mile (2-4°) except where locally disturbed by folds and faults.

The present-day structural framework of Tract C-a is dominated by the Sulfur Creek anticlinal nose and three major en échelon fault systems (graben) on its northeast flank. Four minor folds and multiple subsidiary faults complete the framework.

The Sulfur Creek anticlinal nose is a gentle low relief structure which plunges southeastward (S60¼-70¼E) through the southern portion of the tract. Its axis enters the tract just south of the middle of its western boundary and exits the tract just west of its southeast corner. Core holes AM 2-A and 3 (Amoco) are located on the axis.

The three northwest-trending en échelon graben are essentially parallel to the Sulfur Creek anticlinal axis. The faults bounding the graben are all very

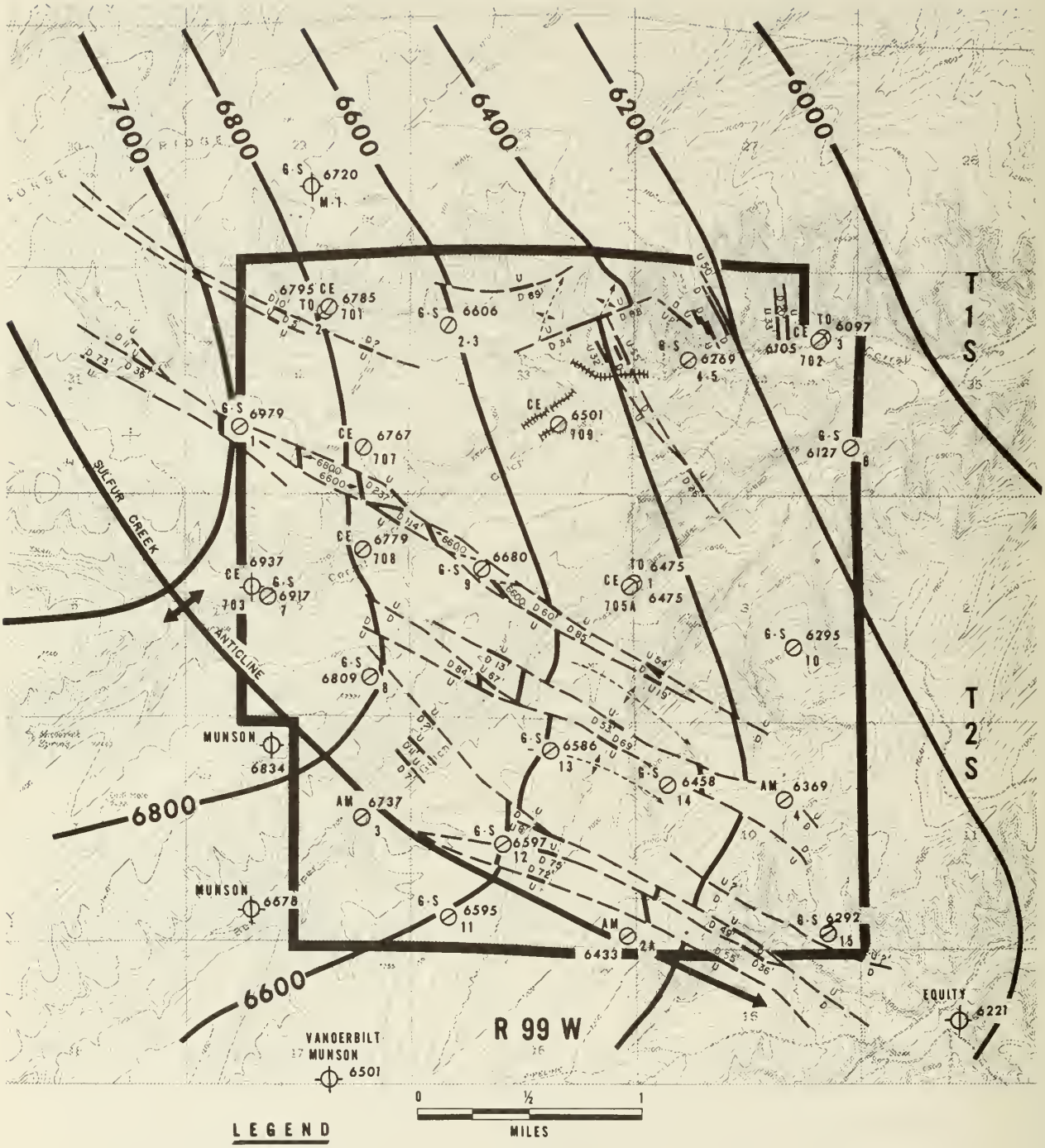


Figure 3-3-5

RBOSP TRACT C-a MIDDLE A-GROOVE STRUCTURE MAP
(Geologic Revision 1)

high angle to near vertical (84°+) normal faults as observed at the surface. Fault displacements range from less than 20' to as high as 237', the latter measured on the most northerly graben at its intersection with Corral Gulch. The graben-bounding fault traces are characteristically sinuous with subsidiary sliver faults branching from them. Direct evidence of cross faulting within the graben is present at the surface in the northern graben at Corral Gulch and the minor drainage southeast of Box Elder Gulch, and perhaps in the central graben at Box Elder Gulch.

The northern graben is the most structurally complex of the three. In addition to the cross faulting defined in this graben, displacements on its north-bounding fault are consistently greater than those on its south-bounding fault (237' versus 114' at Corral Gulch, 85' versus 60' at Box Elder Gulch, and 54' versus 19' at the drainage southeast of Box Elder Gulch). The combination of cross faulting together with differential displacement on the graben-bounding faults provide strong evidence that the graben is not one simple downthrown block but rather a series of broken and tilted (rotated) blocks between the graben-bounding faults. Even further evidence of the graben's complexity is furnished in the subsurface section penetrated by core hole G-S 9.

Core hole G-S 9 was intentionally drilled in the northern graben to more fully define its characteristics (fault displacement, fault zone hydrologic conditions, fracture intensity). The core hole prognosis expected the middle A-groove at a datum of +6600' based on fault displacements observed on the graben outcrops at both Corral and Box Elder Gulches. Instead, the middle A-groove was encountered at +6680, 80' structurally higher than anticipated. Based on the known occurrence of cross faulting in this graben and assuming the graben-bounding faults are vertical, two additional cross faults are interpreted on Figure 3-3-5 in the vicinity of core hole G-S 9. These two additional cross faults define a discrete graben block on which the core hole is located which was not dropped as much as other blocks within the graben; namely, those exposed on Corral and Box Elder Gulches.

In addition, core hole G-S 9 encountered three normal faults and one reverse fault, further evidence of the graben's complexity and the multiple discrete fault blocks within it:

- In the vicinity of this core hole, a normal section of the upper Parachute Creek Member (top Parachute Creek to middle A-groove) is about 460' thick. However, the core hole encountered the Uinta Formation-Parachute Creek Member contact at a depth of about 161' and the middle A-groove at 458', an upper Parachute Creek Member thickness of only 297'. About 160' of uppermost Parachute Creek Member section is therefore absent in this core hole. It was removed by a normal fault with up to that amount of displacement cutting the hole at a depth between 110' and 161'. In this 51' thick interval, about 28' of core was lost suggesting the presence of a highly fractured section associated with a fault.
- At depth 339' to 391', an interval 52' thick in the L-8 zone, about 34' of core was lost, again suggesting a highly fractured shale section associated with a fault. Core recovered from depth 358' to 365' is a text book example of a fault breccia (angular to subangular shale fragments of various sizes cemented in a more finely crushed matrix). In addition, core recovered from depth 375' to 377' exhibits bedding dips of 30°. The thickness of the L-8 zone in this core hole is only about 5' less than that present in nearby core holes. A normal fault with about 5' of displacement is present in this core hole at depth 360'.
- In the R-6 zone, brecciated and highly fractured shale is associated with about 18' of lost core. The R-6 zone is about 30' thinner in this core hole than in nearby core holes. A normal fault with about 30' of displacement is present at a depth of about 610'.
- In the L-5 zone, breccia, slickensides and badly broken core are associated with about 40' of missing core. This zone is about 25' thicker in this core hole than in nearby core holes. A reverse fault with about 25' of displacement is present at a depth of about 780'.

Core hole G-S 9 encountered an interval 700' thick from depth 350' to 1050' in which breccia, slickensides, steep dips, highly broken core (rubble) and offset bedding are concentrated. Evidence of this kind reflects a highly disturbed section due to both faulting encountered in the hole and faulting in near proximity to the hole.

Core hole G-S 1 is also located in the northern graben near the west boundary of the tract. In its uppermost cored interval, depth 43.6' to 211', abundant evidence of faulting is present. This evidence includes bedding planes dipping 15-75° and slickensided fractures dipping 60° to vertical. Below depth 211', this evidence abruptly ends and a relatively undisturbed section is present. In addition, the core hole's L-8 zone is about 15' thinner than in nearby core holes. A normal fault with about 15' of displacement is interpreted cutting the core hole at a depth of about 212'. This fault may be the south-bounding fault of the graben and if so, the fault plane dips about 82° to the northeast.

The central graben appears considerably less complex than the northern graben based on its present definition. Only at its outcrop on Corral Gulch is there possible evidence of major cross faulting and the presence of multiple graben blocks. No great displacement differential has been defined on the graben's north and south-bounding faults to suggest severe tilting (rotation) within the graben.

Core hole AM 4 is located within the central graben near its southeast terminus and adjacent to its north-bounding fault. The core hole encountered five thin intervals of brecciated core from depth 1020' to 1360', the most pronounced of which is from depth 1032' to 1046'. If the uppermost occurrence of breccia at depth 1032' to 1046' is interpreted as the subsurface expression of the north-bounding fault, the fault plane dips 86° to the southwest. Assuming the north-bounding fault is vertical, the five occurrences of breccia are interpreted as minor subsidiary faults within the major graben. Fault displacement is minimal because the thicknesses of the zones in which the breccia intervals occur (R-6 through R-4) appear normal when compared to thicknesses in nearby core holes.

The southern graben is characterized by a pair of north and south-bounding faults and a third fault within the graben subparallel and in relatively close proximity to the north-bounding fault. This third fault joins the north-bounding fault just outside the tract's southern boundary. The total displacement of the internal-graben fault and the north-bounding fault where they outcrop in the drainage southeast of Box Elder Gulch is 103+, down to the

south (28' plus 75'+). Where they outcrop near the tract's south boundary, the total displacement of the faults is 85', down to the south (49' plus 36'). Displacement on the graben's south-bounding fault at the same two outcrop locations are 72'+ and 55', respectively, down to the north. The differential displacement indicated by the relationship of these three faults strongly suggests at least part of the graben is tilted similar to the northern graben. However, no firm evidence of cross faulting has been defined.

Core hole G-S 12 is located within the southern graben just east of the interpreted juncture and terminus of the south-bounding fault with the internal-graben fault. The core hole was intentionally drilled in the graben to more fully define its characteristics. The core hole prognosis expected the middle A-groove at a datum of +6500' based on the vertical faults and their displacements observed at their outcrop about 1000' to the east. Instead, the middle A-groove was encountered at +6597, almost 100' structurally higher than anticipated. Three interpretations are possible:

- The core hole cut the fault immediately to its north at a depth of about 212' based on a lost core interval about 34' thick from depth 208' to 242'. It requires a fault plane dip of 65° to the south intersecting the core hole at depth 212'. The only other significant fault evidence in this core hole is at depth 1025' where a 6' thick breccia interval is present.
- An unexposed cross fault is present between the core hole location and the outcrop about 1000' to the east and the core hole was drilled on a graben block considerably less downthrown than the block exposed on the outcrop.
- Fault displacement observed at the surface diminishes with depth at an average rate of about 14' for every 100' of depth in the vicinity of this core hole because it encountered the middle A-groove 97' structurally higher than the prognosis predicted at a depth of 680' rather than 777' (97'/680' = 0.1426'/1' of depth = 14.26'/100' of depth).

Assuming the faults are essentially vertical as indicated on the outcrop just east of the core hole, either the second or third interpretation is favored by RBOSP. Since no cross faulting can be defined supporting the second interpretation, the third interpretation is shown on the RBOSP structure map (Figure 3-3-5).

In support of the above third interpretation, the concept of fault displacement diminishing with depth requires some explanation. Leroy (1951, p. 53) states that faults observed at the surface may be absorbed by beds in the subsurface and thus have restricted vertical downward extension. They are commonly said to "die out" with depth. As the faults are absorbed, their displacements diminish, eventually decreasing to zero where the faults finally die out. Rocks at or near the surface are under relatively low formation temperature and confining pressure thus behaving as brittle material readily susceptible to fracturing. When subjected to tectonic forces, subsequent movement of rock blocks along these fractures result in faults. Rocks deeper in the subsurface are under relatively higher formation temperature and confining pressure, both increasing with depth, and are more prone to plastic deformation rather than fracturing. In plastic deformation, rocks change their original shape without fracturing. The processes that permit plastic deformation are intergranular movements, intragranular movements and recrystallization (Billings, 1942, p. 20-29).

Cross sectional examples of faults dying out with depth are presented by Leroy (1951, p. 53) and Lahee (1952, p. 219). Lahee's example is particularly noteworthy because it also demonstrates fault displacement decreasing with depth. In the northeast part of Tract C-a, several superficial fault systems have been mapped which appear to affect only rocks within the Uinta Formation (A&I, 1975-B, p. III-3). These faults have displacement up to 50' in the Uinta Formation while in the underlying Parachute Creek Member, no displacement is observed on the outcrop.

In addition to the major surface structures within Tract C-a (Sulfur Creek anticline and the three en échelon graben on its northeast flank), four minor anticlinal noses and multiple subsidiary faults are present at the surface.

The four minor anticlinal noses are all located in near proximity to fault systems strongly suggesting a direct relationship (see Summary of Tectonic History). Two folds are located in the southeast part of the tract between the three major graben and trend subparallel to them. The other two folds are located in the north central part of the tract and trend northeast. They are confined to an area between a pair of east to northeast-trending step faults, down to the south with surface displacements of almost 90'. In this area, erratic dips, slump and distorted bedding (fault drag?) are associated with these folds mapped in the Uinta Formation (A&I, 1975-B, p. V-3). It is not clear at this time whether the fairly complex surface structure mapped in this local area is confined essentially to the Uinta Formation or extends to an appreciable degree into the underlying Parachute Creek Member. In either case, the two folds are probably related to local compressive forces between the two east and northeast-trending faults.

The remaining surface faults within the tract are all relatively minor with displacements at the surface ranging from less than 2' to 50'. Some of these faults are small graben and step faults. The faults with 50' of surface displacement have been discussed previously as those mapped in the Uinta Formation in the northeast corner of the tract which appear to die out before reaching the underlying Parachute Creek Member. Again considering the concept of fault displacement diminishing with depth, many of these faults probably die out before the Parachute Creek Member's oil shale sequence is reached or at least have lesser displacement in the subsurface than exhibited at the surface. Also, structural relief on the four minor surface folds can be expected to be subdued with depth.

2. Joint System - Joints are smooth fractures defined as divisional planes or surfaces that divide rocks, and along which there is no visible movement parallel to the planes or surfaces. A joint set consists of a group of more or less parallel joints. A joint system consists of two or more joint sets with a characteristic pattern.

A&I (1975-B, p. V-7 to V-10) determined joint orientations at 42 outcrop locations within Tract C-a. Since the outcrops varied in size, the number or

frequency of joints counted per foot was adjusted to determine the number of joints present in a 100' long outcrop, thus equating joint data measured at one outcrop with that measured at all others. This adjustment is known as "normalizing" and is based on the following formula:

$$\frac{100'}{\text{length of outcrop}^*} \times \text{number of joints in outcrop} = \text{normalized joints}$$

* length of outcrop measured normal to joint planes

Figure 3-3-6 is a rose diagram which portrays the strikes of joints measured at all 42 outcrop locations or joint stations. The upper half of the diagram shows the average number of normalized joints which strike within each 10° increment of compass direction. This average number was determined by dividing the total number of joints measured which strike within each 10° increment by the number of joint stations. The lower half of the diagram illustrates the equivalent percent of normalized joints which strike within each 10° increment.

Analysis of the joint orientation data indicates a joint system consisting of three main joint sets is present within Tract C-a with joints in each set generally spaced 10' or more apart. The average strike and dip of the sets are as follows:

- The dominant or major set strikes N56°-76°W with dips of 74°SW passing through vertical to 86°NE. The set essentially parallels the axis of the Sulfur Creek anticlinal nose and the three major en échelon graben on its northeast flank. It controlled development of the numerous tributary drainages oriented about normal to the major northeast-trending drainages within the tract.
- The secondary set strikes N28°E with a dip of 80°NW. This set is subparallel to and controlled development of all the northeast-trending drainages including the major Corral Gulch, Box Elder Gulch and the one immediately southeast of Box Elder Gulch.
- The tertiary set strikes N15°W with a dip of 75°E. It controlled development of the northerly oriented tributary drainages on the north side of Dry Fork as well as in other parts of the tract.

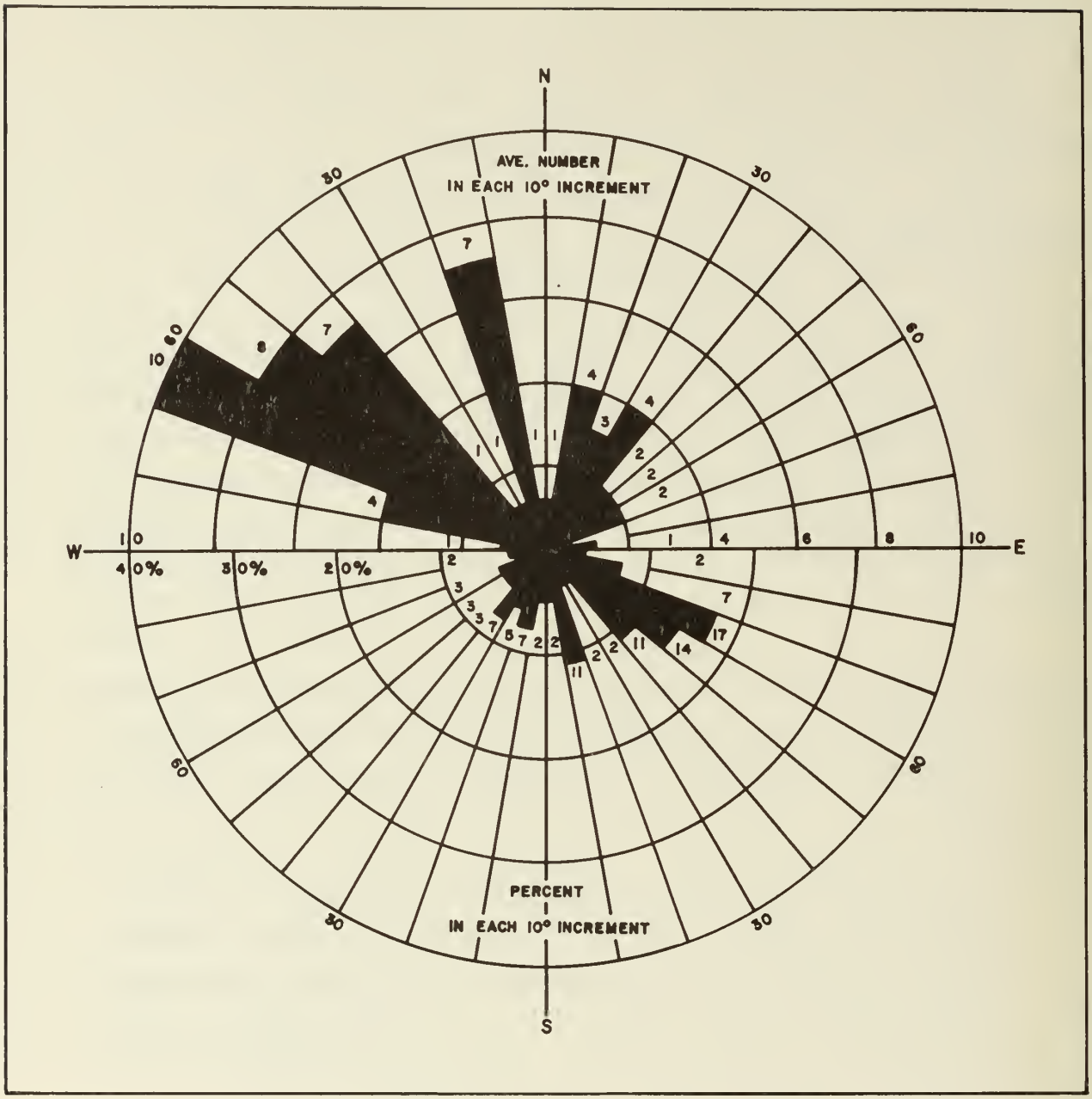


Figure 3-3-6

SURFACE JOINT ORIENTATIONS (STRIKES) WITHIN
TRACT C-a, ROSE DIAGRAM

Development of the east-west oriented Dry Fork drainage in the northwest part of the tract appears to have been controlled by a local fourth joint set striking N84°W and dipping 82°N passing through vertical to 85°S.

Seisviewer log data compiled by A&I (1975-D) in 12 on-tract holes (core holes G-S 2-3, 7, 9, 10, 11, 12, 14, 15 and deep hydrologic test holes D-16, 17, 18 and 19) were analyzed by M-K (1975) for subsurface orientation of joints. Their analysis indicates:

- Joints are widely spaced, strike either northeast or northwest and primarily dip at angles greater than 60°.
- The number of joints tends to decrease with depth.
- Lean zones tend to have slightly more joints per foot of thickness than the rich zones.
- Lateral continuity of joints is poor. Core hole G-S 12 and hydrologic hole D-16, which twin each other, have joints independent of one another.

In reference to the last item above, it should be pointed out that G-S 12 and D-16 are both located in the southern graben near the internal-graben fault. The interpreted lateral discontinuity of joints between these two holes may be the result of differentially developed fracturing associated with this fault.

3. Alluvium Slump - Shown on Figure 3-3-5 are the traces of three very recent valley alluvium slump features in the vicinity of the confluence of Corral Gulch and Dry Fork in the north central part of the tract. The northern trace trends eastward and parallels the Dry Fork road. The two southern traces trend southwestward in the vicnity of core hole CE 709; one immediately adjacent to the core hole location, the other paralleling the Corral Gulch road. These features are cracks or fissures in the alluvium, as much as 6' deep, generally in a zone 7' to 10' wide extending several hundreds of feet in length.

These features were first noted in April, 1975. Investigation concluded that they were not present in late 1974 prior to snow cover (O'Hara, 1975). A

search of the tract for similar features disclosed a minor one present in the vicinity of core hole CE 708, about one foot deep and about 85' in length. Further, a discussion with Mr. G. Saulnier of the USGS Water Resources Division revealed that he had observed features similar to and in the same general vicinity of those recently observed on Tract C-a in the late spring of 1973 prior to the lease sale.

The traces of these features appear to be limited to valley alluvium and not associated with bedrock. Displacement along them is horizontal and vertical, both toward the stream bottom side. They appear to be tension cracks along which the alluvium has subsided or collapsed streamward and are perhaps related to spring thaw and run-off.

4. Summary of Tectonic History - The present-day structural framework of Tract C-a was initiated during post-Uinta Formation time by renewed arching of the southeast plunging Sulfur Creek anticlinal nose by either major vertical or compressive tectonic forces. The Sulfur Creek nose is an old feature, pre-Parachute Creek, as evidenced by its isopach thin in the A-groove to Blue marker interval (RBOSP, regional control).

The arching caused tensional forces to develop in the shallow near-surface rocks, a stretching effect, resulting in the development of a major set of joints or fractures oriented in a preferred direction parallel to the Sulfur Creek anticlinal axis. Minor joint sets also developed oriented about north and northeast.

The tensional forces were greater in the near-surface rocks than in progressively deeper buried rocks. Nearest the surface, the more brittle rocks ruptured because of relatively low formation temperature and confining pressure. In the progressively deeper sections, the rocks tended to change their original shape by plastic deformation because of the relatively higher formation temperature and confining pressure, both progressively increasing with depth.

Essentially vertical, high angle normal faults developed in the ruptured near-surface rocks, pairs of which formed the bounding-faults of the three major en échelon graben on the northeast flank of the anticlinal nose. Blocks between

the bounding-faults collapsed by gravity, some being rotated (tilted) and broken by cross faulting. The graben served as major relief adjustments to the overstrained near-surface rocks on the anticlinal nose. They formed either during or immediately after the arching.

The other faults within the tract developed as subsidiary relatively minor relief adjustments possibly subsequent to the more major graben. Locally contained compressive forces between some of the faults caused minor folds to develop as tectonic activity came to rest.

3.4 IN-PLACE TRACT RESOURCES

Using both pre-lease and new core hole data, RBOSP has made an estimate of total oil "resource" contained within Tract C-a. An estimation of total in-place tract resources is believed essential to an evaluation of various mining and processing options considered. Rio Blanco's estimates of total in-place tract resources have been provided, therefore, to the AOSS; however, Rio Blanco believes that this estimate is confidential and proprietary, and therefore these data have been incorporated into the confidential section of this report. It is pertinent to note, however, that our definition of in-place tract resources includes all oil shale intervals 10 feet thick or more and averaging 8 GPT or more of contained oil*; further, that all oil shale encountered in the L-8 down through L-00 zones was included if it exceeded this grade cutoff. The horizontal extent of the estimated tract resources was considered to be all material within the vertical projection of the tract boundaries.

3.5 OVERBURDEN

Overburden thickness between ground surface and the middle A-groove horizon varies considerably throughout the tract dependent upon abrupt local changes

*Grades of intervals 10' thick are the thinnest units used in the computer-generated mineral model to define the tract oil shale deposit. The 8 GPT cutoff is predicated on the indication that grades below this would not, upon retorting, yield energy equal to that required for production by present-day technology.

in topographic relief. This variable topography together with the general east and northeast gentle dip of the subsurface middle A-groove horizon result in a generally northeast trending "grain" to the overburden.

The middle A-groove was selected as the base of the overburden interval because it:

- Marks the top of the main oil shale interval as defined on Figure 3-3-4.
- Is in near proximity to the top of the Mahogany zone, the most shallow of the richer shale zones within the tract.
- Is the key structural marker selected for the tract's subsurface structural mapping as shown on Figure 3-3-5.

Overburden ranges from about 60' to 875' with a tract average of 482' as determined by planimeter. The least overburden is on the far west edge of the tract in Dry Fork and Corral Gulch. The maximum overburden is on the tract's north border atop the ridge due north of core hole G-S 4-5.

In the various core hole programs within the tract, the least overburden was encountered in core hole G-S 7 where the middle A-groove was penetrated just 72' below ground surface. This core hole is located near the west edge of the tract in Corral Gulch. The maximum overburden was encountered in core hole AM 2-A where the middle A-groove was penetrated 812' below ground surface. This core hole is located just inside the tract's southern border on a prominent northeast-trending ridge.

Overburden consists of (1), bedrock of the upper Parachute Creek Member of the Green River Formation and the overlying Uinta Formation and (2), unconsolidated sediments comprised of valley alluvium, colluvium and soil cover.

The upper Parachute Creek Member consists of light gray to medium brown marlstone (oil shale) of the upper AG, R-8 and L-8 zones shown on Figure 3-3-4 grading upward into light gray barren marlstone interbedded with gray siltstone and fine-grained sandstone. Outcrops of this unit form the light gray canyon

walls in the tract's major drainages. The overlying Uinta Formation consists mainly of brown to light brown fine-grained massive sandstones with lesser amounts of siltstone.

Unconsolidated sediments include valley alluvium consisting of brown soil with varying amounts of poorly sorted rock fragments and colluvium consisting of talus slopes of relatively coarse rock fragments. Soil cover is thickest in the valleys and thinnest on the ridge lines and steep slopes.

3.6 CONVENTIONAL OIL AND GAS TESTS & LEASES

A. Tests - Shown on Figure 3-3-7 are the locations of the 6 conventional oil and gas tests drilled within or in near proximity to Tract C-a. Two wells were drilled within the tract, one each by British American and Occidental. The British American well is located about 20' southwest of the AM 3 core hole in the southwest part of the tract. The Occidental well is located about 300' southeast of the CE 702 core hole in the northeast corner of the tract. Equity drilled one well just southeast of the tract and Munson and Vanderbilt-Munson drilled three just outside the tract near its southwest corner.

Listed below are summaries of these wells. The wells are listed in the sequence drilled to provide a chronologic history of oil and gas exploration in the Tract C-a area. The depth of the Orange marker (OM) is given in each well as a stratigraphic reference point so that the depth of any oil and gas show and drill stem test (DST) can be related to the base of the lowermost zone (L-00) of the tract's oil shale sequence as portrayed on Figure 3-3-4. Also shown in parentheses is the depth of the most shallow reported oil and gas show or test below the Orange marker.

- Equity No. 1 Corral Gulch
  SE NW Sec. 14, T. 2 S., R. 99 W.
  Spud: 8/16/57.
  Completed: 9/14/57, plugged and abandoned.
  TD: 6071' in Mesaverde Fm.
  OM at depth 1615'.
  Shows and Tests:

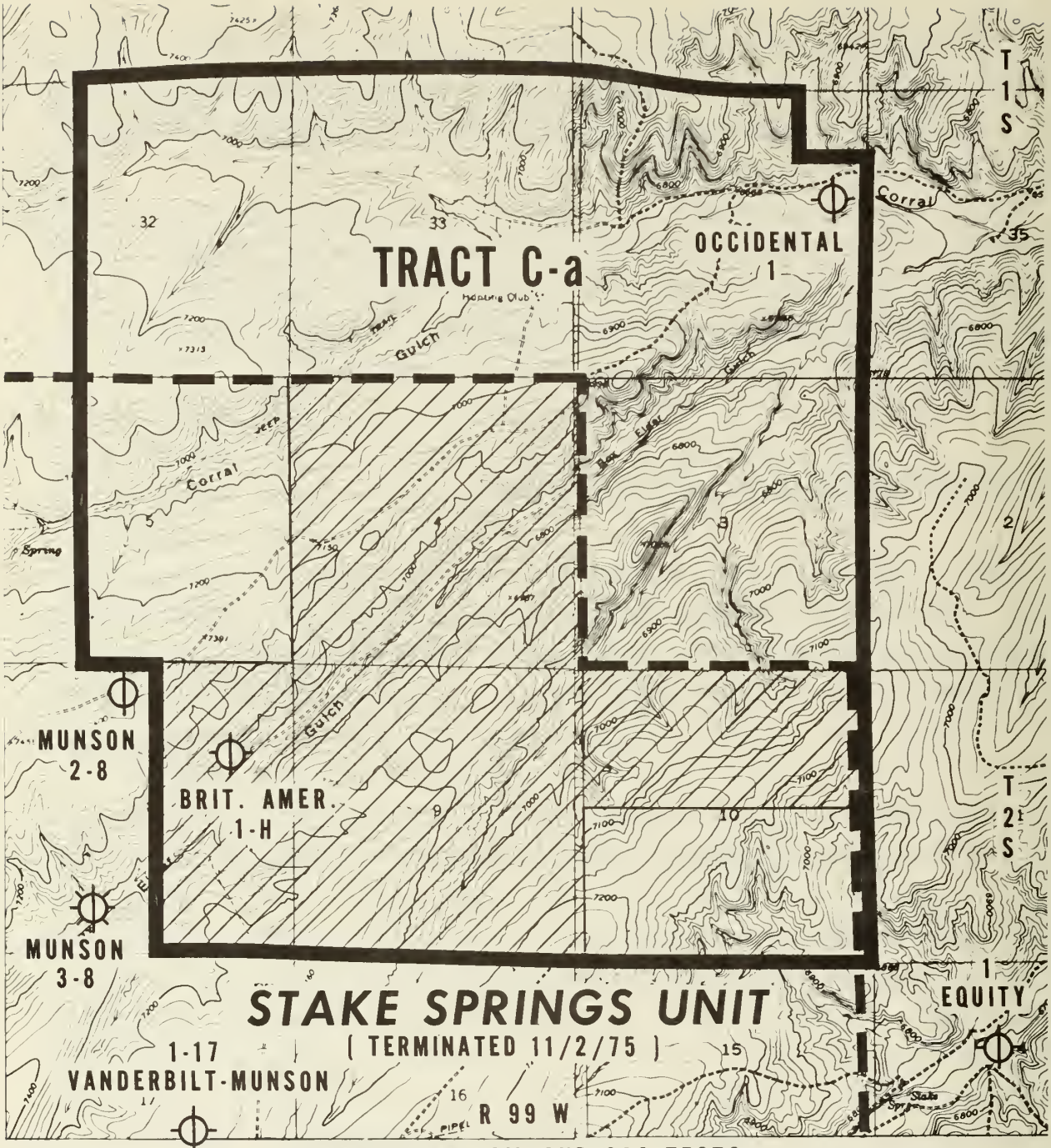


Figure 3-3-7

CONVENTIONAL OIL-GAS TESTS AND LEASES
TRACT C-a

- DST 3831-3895' (2216' below OM) in Wasatch Fm.; recovered 120' of slightly gas cut drilling mud.

- DST 4095-4176' in Fort Union Fm.; gas to surface in 7 min. at 340 MCF/D, decreased to 100 MCF/D; recovered 720' of gas cut drilling mud and 1630' muddy salt water.

- DST 4737-4820' in Fort Union Fm.; recovered 780' of gas cut and water cut drilling mud.

- DST 5900-6071' in Mesaverde Fm.; no recovery.

- DST 5730-6071' in Mesaverde Fm.; gas to surface in 18 min. too small to measure, recovered 240' of gas cut drilling mud.

- DST 5175-5260' in Mesaverde Fm.; recovered 200' of drilling mud, no shows.

- British American No. 1-H Govt. Carter
  SE NE Sec. 8, T. 2 S., R. 99 W.
  Spud: 7/15/58.
  Completed: 8/31/58, plugged and abandoned.
  TD: 5526' in Mesaverde Fm.
  OM at depth 1284'.
  Shows and Tests:

  - Questionable oil stain at 2250' (966' below OM) in lower Green River Fm. or upper Wasatch Fm.; no test.

  - Spotty oil stain at 2500' in lower Green River Fm. or upper Wasatch Fm.; no test.

  - Slight oil stain and gas odor at 3050' in Wasatch Fm.; DST 3034-3071'; recovered 60' of drilling mud and 30' of slightly gas cut drilling mud with a scum of oil.

  - Dead oil stain at 4380' in Fort Union Fm.; DST 4295-4390'; flowed gas to surface in 25 min. at 180-230 MCF/D, recovered 350' of gas cut drilling mud.

  - Dead oil stain at 5300' in Mesaverde Fm.; two DST's, 5072-5326' and 5067-5326' recovered 420' and 300' of gas cut drilling mud, respectively.

  - Ran pipe to 5513', perforated 3 zones, stimulated with sand-frac, ran production tests:
    .From 5288-5502', Mesaverde Fm.; flowed gas, too small to measure.
    .From 4172-4478', Fort Union Fm.; swabbed water with some gas.
    .From 3840-4120', Fort Union Fm.; swabbed, no fluid recovered.

- Occidental No. 1 Cascade-Govt.
  SE NE Sec. 34, T. 1 S., R. 99 W.
  Spud: 9/3/69.
  Completed: 10/26/69, plugged and abandoned.
  TD: 6433' in Mesaverde Fm.
  OM at depth 1720'.
  Shows and Tests:
  - Oil stain at 2860-2870' (1150' below OM) in Wasatch Fm., no test.
  - Oil fluorescence at 5990-6080' in Mesaverde Fm., no test.

- Vanderbilt No. 1-17 Munson
  NW SE Sec. 17, T. 2 S., R. 99 W.
  Spud: 7/27/72.
  Completed: 8/16/72, plugged and abandoned.
  TD: 5260' in Mesaverde Fm.
  OM at depth 2030'.
  Shows and Tests:
  - DST 2856-2906 (826' below OM) in Wasatch Fm.; recovered 40' of drilling mud, no shows.
  - DST 3697-3720' in Wasatch Fm.; recovered 240 barrels of drilling mud and mud cut salt water, no shows.

- Munson No. 2-8 Stake Springs Unit
  NE NW Sec. 8, T. 2 S., R. 99 W.
  Spud: 7/1/73.
  Completed: 7/31/73, temporarily abandoned.
  TD: 5033' in Mesaverde Fm.
  OM at depth 1706'.
  Shows and Tests: None reported.

- Munson No. 3-8 Stake Springs Unit
  SE SW Sec. 8, T. 2 S., R. 99 W.
  Spud: 7/15/74.
  Completed: 5/21/75, shut in gas well.
  TD: 5080' in Mesaverde Fm.
  OM at depth 1430'.
  Shows and Tests:
  - DST 4908-4975' (3478' below OM) in Mesaverde Fm.; recovered 93' of slightly gas cut drilling mud and 97' of drilling mud.
  - Ran pipe to 5050', perforated 4914-4924', 4962-4970', 4990-4996', stimulated with acid and sand-frac, initial potential 15 MCF/D gas from Mesaverde Fm.

B. Leases - Tract C-a is covered entirely by conventional Federal oil and gas leases. The northeastern part of the Federal Stake Springs Unit extends into the tract's southern portion as shown by its dashed outline on Figure 3-3-7. This unit was formed effective July 7, 1972, with D. M. Munson as the unit operator. The unit was automatically terminated effective November 2, 1975.

All Federal leases within Tract C-a, except those shown diagonally lined on Figure 3-3-7 contain the following four-part stipulation pertaining to oil shale:

- No wells will be drilled for oil or gas except upon approval of the Regional Oil and Gas Supervisor of the Geological Survey, it being understood that drilling will be permitted only in the event that it is established to the satisfaction of the Supervisor that such drilling will not interfere with the mining and recovery of oil shale deposits or the extraction of shale oil by in situ methods or that the interest of the United States would best be served thereby.

- No wells will be drilled for oil or gas at a location which, in the opinion of the Regional Oil and Gas Supervisor of the Geological Survey, would result in undue waste of oil shale deposits or constitute a hazard to or unduly interfere with mining or other operations being conducted for the mining and recovery of oil shale deposits or the extraction of shale oil by in situ methods.

- When it is determined by the Regional Oil and Gas Supervisor of the Geological Survey that unitization is necessary for orderly oil and gas development and proper protection of oil shale deposits, no well shall be drilled for oil or gas except pursuant to an approved Unit plan.

- The drilling or the abandonment of any well on this lease shall be done in accordance with applicable oil and gas operating regulations including such requirements as The Regional Oil and Gas Supervisor of the Geological Survey may prescribe as necessary to prevent the infiltration of oil, gas, or water into formations containing oil shale deposits or into mines or workings being utilized in the extraction of such deposits.

The Federal leases which are diagonally lined have an expiration date of August 2, 1977.

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CHAPTER 4

HYDROLOGY

SECTION 3
BASELINE CONDITIONS

CHAPTER 4
HYDROLOGY

The determination of the hydrologic baseline is required for both environmental and engineering studies pertinent to the development of Tract C-a. This baseline includes both the surface and subsurface hydrologic environments. The determination of water quality, quantity, location, and movement is of prime interest to both disciplines. The main environmental concerns include: surface and subsurface hydrologic conditions as they exist today in the Tract C-a area; and the effects of mining and the associated dewatering on these conditions in the vicinity of the mine and throughout the Piceance Creek basin. The baseline conditions have been used for engineering studies in determining: mine designs; mine dewatering schemes; flood protection measures; quality and quantity of water produced and available for processing and processed shale disposal; and design of diversion structures and culverts.

The determination of the baseline conditions was done through studies of precipitation, springs and seeps, surface water, alluvial aquifers and deep bedrock aquifers. This chapter summarizes the data collection programs and results of these studies. In addition, a summary of data available on the regional hydrology is included. The basic raw data have been submitted to the AOSO in quarterly progress reports, which are available for inspection in that office.

4.1 GENERAL

A. Final Environmental Statement for the "Prototype Oil Shale Leasing Program" - The Final Environmental Statement published by the U.S. Department of Interior in 1973 summarizes the information available prior to 1972 as pertinent to the hydrology of Piceance Creek basin. Several items of particular interest from this document are mentioned below.

- Possible Hydrologic Environmental Impacts:

  - Reduced surface and spring flow due to dewatering.
  - Disturbance of surface and spring flow in mining area.
  - Reduced salinity of the Colorado River due to reduced flows from Piceance Creek basin.
  - Pollution to existing surface water by: leaching of processed shale; erosion in disturbed areas; industrial spills; and failure of impounding ponds.

- Hydrologic basin versus Geologic basin - The term Piceance Creek basin can have two connotations: the first referring to the geologic basin, which includes parts of Moffat, Rio Blanco, Garfield, Gunnison and Mesa counties. The second is the hydrologic basin, which is much smaller areally than the geologic basin. The hydrologic basin is bounded on the north by the White River, on the east by Colorado Highway #13, on the south by the Roan Plateau, and on the west by Cathedral Bluffs, and covers an area of 900 square miles. Therefore, areas such as Parachute Creek, which are included in the geologic basin, would be excluded from the hydrologic basin as shown in Figure 3-4-1.

- Precipitation:

  - 7 - 24 inches/year range across basin.
  - Slightly less than 1/2 of the precipitation occurs as snow.
  - Flash floods occur, predominantly during late summer from thunderstorms.

- Springs and Seeps:

  - 37 springs located within 40,000 foot radius of Tract C-a.
  - Springs receiving their water from perched aquifers would not be affected by Tract C-a dewatering.

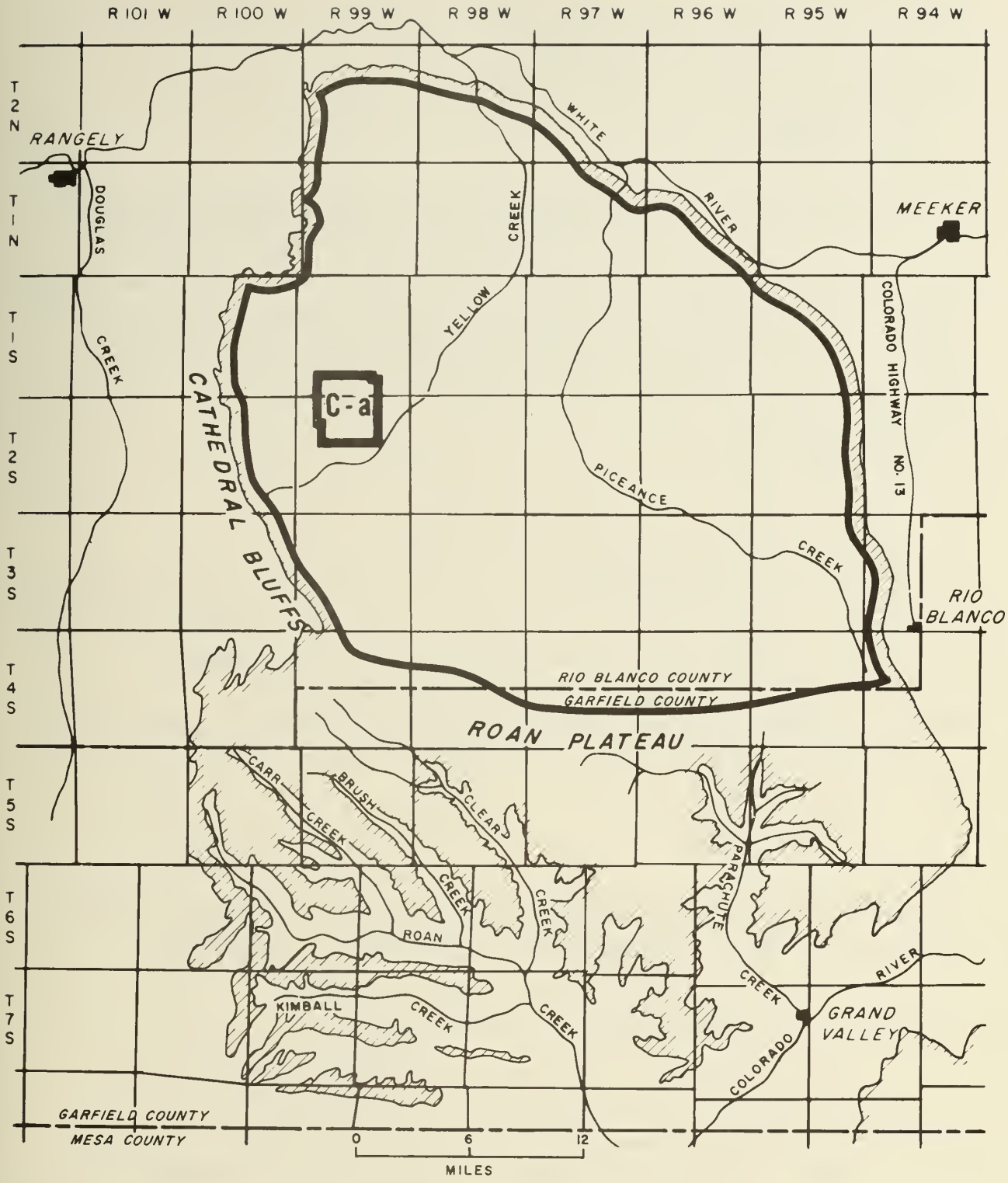


Figure 3-4-1

PICEANCE CREEK HYDROLOGIC BASIN

- Other springs would suffer reduced flow, or would be dried up, due to mine dewatering.

- Streams:

  - Most streams are ephemeral; i.e., don't sustain flows except during periods of snowmelt and runoff from thunderstorms.
  - Piceance Creek and the lower reach of Yellow Creek are perennial.
  - Water quality is variable depending on amount and quality of ground water discharge to a given reach of the stream.

- Alluvium:

  - Occurs in the valley bottoms.
  - Usually less than 1/2-mile wide.
  - 0 - 140 feet thick.
  - Alluvial water level generally less than 40 feet deep.
  - Water table shallow enough to support phreatophytes.
  - Total dissolved solids 250 - 25,000 mg/l.
  - Has produced up to 2,000 gpm from wells for a short period of time.

- Deep Aquifers:

  - Green River Formation (including Uinta Formation*) is the best source of ground water in the Piceance Creek basin.
  - 25 million acre-feet of water in storage.
  - Mahogany zone relatively impermeable.
  - Two aquifers, separated by the Mahogany zone.
  - Dissolved solids varying from 250-63,000 mg/l.
  - Recharge from precipitation around the margin of the basin.
  - The head difference between the two aquifers is up to 130 feet.
  - Transmissivity of the upper and lower aquifers varying from 300 to 1,000 and 3,000 to 10,000, respectively.

*Formerly the Evacuation Creek Member of the Green River Formation.

The Final Environmental Statement was determined to contain generally correct information as defined by our subsequent hydrologic baseline studies, with the exception of the upper oil shale aquifer stratigraphic location and hydrologic properties. These differences are discussed in Item 4.4 of this chapter.

B. Lease Stipulations - The Tract C-a lease defines a number of surface water and ground water parameters which must be monitored.

Those parameters for surface flow include both quality and quantity at stations located on the major drainages upstream and downstream of Tract C-a. Data to be collected on a continuous basis are flow, water temperature, precipitation and sediment. The lease further stipulates that periodic analysis for inorganic and organic constituents, as directed by the Mining Supervisor (AOSS), shall be completed.

With respect to ground water, the Tract C-a Oil Shale Lease outlines the following programs:

- Drill a test well and observation wells penetrating each water bearing zone, as defined by the test well, at each proposed mine site. Collect samples of the drill cuttings and run bore hole geophysical logs.
- Isolate each water-bearing zone.
- Pump each of the zones.
- During the pumping test, record water level fluctuations in the observation wells. Maintain steady, continuous discharge from the test well.
- Maintain records of water level and temperature from the pumped well and observation holes.
- Collect water samples at the beginning of each pumping test for analysis of water quality, including organic and inorganic chemical constituents, trace constituents subject to drinking water standards and water pollution control regulations.
- After initial testing, collect water samples from each well at 6-month intervals and analyze for evidence of trends in water quality.

- Drill one observation well up-gradient from each disposal site and at least two down-gradient from each site.
- Maintain records of all information.

C. Exploratory Plan - In May, 1974, the Federal Tract C-a Exploratory Plan was completed and submitted to the Oil Shale Mining Supervisor (AOSS). The hydrology portion was divided into surface water monitoring and subsurface hydrology.

The surface water monitoring program included the items that were required by the Oil Shale Lease. In addition, the USGS, under a contract with the Colorado River Water Conservation District, was operating five surface water gaging stations.

The Exploratory Plan includes the following data collection and analysis:

- Automatically record water flow rate.
- Monitor sediment discharge.
- Automatically record water temperature.
- Automatically record specific conductance.
- Install three stations capable of monitoring rainfall intensity.
- Collect water quality samples weekly for four weeks to determine trace elements and future sampling procedures.

Ground water hydrology was broken down into three distinct systems. These were the surface alluvial aquifer, the upper artesian aquifer and the lower artesian aquifer. The purpose for conducting subsurface hydrologic studies was to better define the nature of these aquifer systems. Some of the items to be included were water table evaluations, piezometric surface elevations, areal effects of pumping, water quality, and the physical characteristics of aquifers.

The alluvial data were to be derived from 12 alluvial aquifer observation holes. All but one of these were to be completed off-tract around its perimeter.

A total of 26 deep artesian aquifer holes were to be completed. All but one of these would be completed on tract. This hole would be located north of the tract. The 26 deep observation holes would be designed to penetrate both the upper and lower aquifers, however, the aquifers would be hydraulically isolated within each observation well.

It was anticipated that four of the observation holes would be used for pumping tests in the deep aquifer zones. The two deep aquifers would be tested separately. These pumping tests were anticipated to last for several days and that the length of each would be established as drawdown data were obtained. Fluid pressures or levels would be monitored from each of the aquifers in the observation holes prior to the tests to determine if the packers were leaking. Water samples would be collected at the initiation of each test and periodically during the test.

During the drilling or coring, water samples were to be collected every 200 feet. Three samples, one representing the section above the Mahogany and two below the Mahogany would be analyzed to determine the variation of water quality with depth.

The analysis was to include calculations of transmissivities, hydraulic conductivities (permeabilities), and coefficients of stroage. In addition, hydraulic gradients and variations in water quality would also be determined.

Comparisons were to be made relating hydrologic and geologic data. The geologic data would include faulting, fracturing, jointing, lithology, and general structure. In addition, areas of ground water recharge and discharge were to be identified.

The ground water monitoring program was designed to analyze baseline conditions after the initial water samples were obtained from the drilling and pumping test programs. Samples were to be collected monthly from all of the test holes for a period of six months. In addition to collecting samples, water levels or pressures were to be measured by means of continuous recording equipment in the deep aquifer holes. The alluvial aquifers were to be measured monthly for a

period of one year and then the measurement frequency would be reduced to once every six months.

D. Area Oil Supervisor Approval - After the submission of the Exploratory Plan, approvals by the AOSS for the various hydrologic baseline programs were received. Hydrologic studies were initiated in March 1974. As the program progressed, minor modifications were required from time to time. These approvals with the modifications were accepted by RBOSP and, at the appropriate time, the tasks were conducted.

Modifications of the hydrology section of the Exploratory Plan as required by the Area Oil Shale Supervisor included:

- Three storage rain gaging stations were added to the program along the western Tract C-a boundary.
- Three additional alluvial monitor holes were added to the program and the location of some of the other proposed alluvial monitor holes were changed.
- Four additional deep aquifer monitor holes were added to the program for the 84 Mesa area.
- Three large diameter lower oil shale aquifer pumping test holes were added to the program.

4.2 REGIONAL AND PRE-LEASE DATA

A. Regional Hydrologic Settings - Several publications are available on the hydrology of Piceance Creek basin. Four key publications, prepared by the USGS - WRD in cooperation with the Colorado Department of Natural Resources, are:

Ground Water Circular No. 12, 1968.
HA 370, 1971.
Water Resources Basic Data Releases, 1974;

No. 31 (Data from 1972 and prior years).

No. 35 (Data from 1973 and 1974).

USGS Professional Paper 908, 1974.

The first two publications, published prior to 1972, were used extensively in preparation of the Final Environmental Statement. The Basic Data Releases are compilations of public hydrologic information in the Piceance Creek basin. They also form the data base for Professional Paper 908.

During the past 10 years, many data have been collected and published on the hydrology of the Piceance Creek basin. As previously discussed, the geologic basin encompasses a much larger area than the hydrologic basin. For the purpose of this report, only the hydrologic basin will be discussed in detail. The hydrologic basin is part of a synclinal basin with a northwest-trending axis. The edges of the basin are formed by cliffs which act as hydrologic boundaries defining the hydrologic basin, with the exception of the Roan Plateau which is a ground water divide. This ground water divide separates the structural basin into two hydrologic basins.

The geology is discussed in detail in Section 3, Chapter 3. Briefly, there are three stratigraphic units that play an important role in the hydrologic basin. The Parachute Creek Member of the Green River Formation, which is composed primarily of kerogen-bearing marlstone (oil shale), is the lowest. It is this stratigraphic unit that contains the two deep bedrock aquifers, hereafter called deep oil shale aquifers in the vicinity of Tract C-a. Above the Parachute Creek Member lies the Uinta Formation, previously known as the Evacuation Creek Member of the Green River Formation. This stratigraphic unit is the uppermost bedrock unit in the vicinity of Tract C-a. The youngest stratigraphic unit of interest from a hydrologic standpoint is the Quaternary alluvium.

Geologic structure also has a very important role in the hydrology of the Piceance Creek basin. The Green River and Uinta Formations are cut by extensive joint and/or fracture systems. Not only are the surface streams affected by these joints and fractures, but also water movement in the deep oil shale aquifers appears to be controlled by these structural features. In addition,

faults are present throughout the basin. It appears that these faults play an important part in the hydrology of the Tract C-a area.

Professional Paper 908 brings the major hydrologic facets together into one comprehensive report. It is from this report and its supporting data that RBOSP has derived the hydrologic baseline outside of the Tract C-a area. The two main areas of the report are: The hydrologic system, which summarizes the data base; and the watershed and ground water hydraulics models.

The surface water and ground water baselines were established from 50 surface data sites and over 100 wells. These data included water quantity and quality; and geophysical well log data. In summary, the main points are:

- Streams:
  - Basin runoff to the White River is estimated to be 15,650 acre-feet per year from Piceance Creek and Yellow Creek.
  - 80 percent of the runoff is derived from ground water discharge, and 20 percent directly from precipitation runoff.
  - Piceance Creek runoff is greatly reduced by irrigation; this reduction in runoff is estimated to be 4,740 acre-feet per year.
  - Yellow Creek runoff is only slightly reduced by irrigation; this reduction in runoff is estimated to be 60 acre-feet per year.
  - Basin runoff water quality is affected by irrigation and ground water discharge.
  - Surface water is generally not potable, but is acceptable for livestock watering.
  - Salinity and sodium hazards are high for irrigation.
- Deep Oil Shale Aquifers:
  - There are two principal bedrock aquifers, separated by the Mahogany zone.
  - Recharge to the aquifers occurs mainly above 7,000 feet along the basin margins.

- Water from the aquifers is eventually discharged to evapotranspiration and into the stream systems.
- The watershed model was used to predict effects of precipitation changes on the hydrologic system.
- Each 10 percent change in precipitation resulted in a 40 percent change in ground water recharge.
- The ground water model was used to predict effects of mine dewatering on the hydrologic system.

- Basin Model - In that the ground water model was developed prior to any specific mining plans, only hypothetical dewatering plans were run. Therefore, RBOSP developed a similar model to determine mine dewatering and regional effects as discussed in Section 4, Chapter 3.

B. Pre-Lease Core Hole Drilling - Prior to the leasing of Tract C-a, informational oil shale drilling was conducted on and around Tract C-a in 1971, 1972 and 1973. Some very significant hydrologic data were obtained from each of the programs, indicating that basically two bedrock aquifers exist in the oil shale sequence within Tract C-a. The upper aquifer was found to have a higher piezometric level than the lower over most of the tract, except in the extreme northeast corner of the tract, where the piezometric level of the lower aquifer is higher than that of the upper aquifer. At the request of the USGS, the completed holes from each of the programs were left open. These open holes have resulted in the commingling of waters from the two aquifers with differing piezometric levels. Significant pre-lease hydrologic programs and data collected are described below:

- Cameron Engineers, Inc. conducted a five-hole oil shale drilling program, including CE 701, CE 703, CE 704 C, CE 705 A and CE 706, in the latter part of 1971, in conjunction with Interior's informational drilling program prior to oil shale lease tract nominations. During this five-hole program, two holes were core drilled and one was plug drilled on what is now Tract C-a. The hydrologic data collected during that informational drilling program established the existence of two significant oil shale aquifer systems within Tract C-a.

Following lease tract nominations and the selection of Tract C-a as an oil shale lease tract, Cameron Engineers, Inc. drilled four more informational core holes on Tract C-a during the summer of 1972. Hydrologic data were collected during the drilling. In addition to monitoring the drilling, packers were set in a number of the previously completed holes in order to collect water level data from the two aquifer systems independently.

From these two exploration programs, it was determined that two significant aquifers were present under Tract C-a. The upper aquifer system was found to be variably located, above and below, as well as in, the Mahogany zone. The lower aquifer includes the highly vugular R-3 zone, but its upper and lower boundaries are also stratigraphically variable. The lower boundary in places is the Blue marker, which is the base of the Parachute Creek Member.

Transmissivity, in the upper aquifer system, was determined by prelease exploration to average 5,000 gpd/ft. An average water quality of 900 mg/l dissolved solids was determined.

The lower aquifer system was found to have an average transmissivity of 10,000 gpd/ft. and an average water quality of 2,700 mg/l dissolved solids. The static water level of the lower aquifer system was found to be approximately 200 feet lower than that of the upper aquifer system except in the northeast corner of the tract. Both aquifer systems have water gradients which slope basinward towards the northeast.

During the summer of 1973, Amoco Production Company completed three core holes on the southern portion of Tract C-a. In addition to the data gained from the coring program, 24-hour pumping tests were attempted or completed in each of the three core holes for both the upper and lower aquifer systems. The upper aquifer system had an average transmissivity of 2,200 gpd/ft., but, it should be noted that

for the three tests, the values were 500, 1,000 and 5,000. The lower aquifer system was found to have an average transmissivity of 17,000 gpd/ft.; however, in this case, the values for the three tests were 15,000; 16,000 and 20,000.

The coefficient of storage for the upper and lower aquifer systems were found to be in the order of 10^{-4} and 10^{-5}, respectively. These values definitely indicated that both aquifer systems are under artesian conditions.

- The Oil Shale Corporation (TOSCO) drilled three core holes on Tract C-a in late summer and fall of 1973. These holes twinned previous core holes drilled by Cameron Engineers. The files of the Area Mining Supervisor, Department of Interior, Geological Survey contain no hydrologic data from these TOSCO holes.

4.3 RBOSP BASELINE PROGRAM AND DATA

In order to design the necessary hydrologic baseline program, it was determined that three areas of study were needed. These areas are the surface water system, the alluvial aquifer system and the deep oil shale aquifers. Two specific areas are being intensively studied. They are: Tract C-a where mining of oil shale is to take place; and the 84 Mesa area, the proposed processed shale, sub-ore and overburden disposal site.

The surface studies include the collection and analysis of precipitation, stream flow and water quality data. Six precipitation gages have been located at various points on and around Tract C-a. On all of the significant surface drainages entering or leaving the tract, surface water gaging stations have been built. Two stations are located on drainages which are more remotely connected with the tract and activities associated with it. The locations of these precipitation gages and surface water gaging stations are shown in Figure 3-4-2.

Adjacent to most of the surface water gaging stations are alluvial monitor holes. These holes were drilled to gain data and establish baseline parameters for the alluvium. A total of 15 alluvial monitor holes have been completed to date. Their locations are shown in Figure 3-4-2.

The deep oil shale aquifer exploration program was combined with the core drilling program. These holes, plus the holes drilled by pre-lease operators, were used as monitor holes or were plugged and abandoned. In addition, four larger diameter holes were drilled and used for pumping tests of the lower aquifer.

Deep oil shale aquifer baseline data were collected from the drilling programs, formal pumping tests and the monitoring program. This data includes aquifer locations, characteristics and water qualities.

Figure 3-4-3 summarizes the hydrologic program. The surface water monitoring and data collecting have been carried out primarily by the Water Resources Division of the USGS. However, some data have been collected by NUS in conjunction with the Aquatic Biology Program Section 3, Chapter 8. With the exception of the Exploratory Plan and the above-mentioned work, the remainder of the hydrologic program was done under the supervision of Wright Water Engineers, Inc. Table 3-4-1 shows the month that each of the baseline monitoring programs was initiated.

The following is a list of terms used:

- Aquifer - A stratum or zone below ground level that contains sufficient saturated permeable material to yield significant quantities of water to wells or springs.
- Artesian Condition - The condition where the piezometric surface is higher than the top of the aquifer, that is, water pressure within a confined aquifer causes water to rise, in a test hole, above the top of the aquifer.

- Coefficient of Storage (S) - The volume of water released or taken into storage, per unit surface area, when the head on the aquifer is changed by one unit; or the amount of water released from one square foot column of saturated aquifer, in place, when the head on this column is reduced by one foot. The coefficient of storage is referred to as the specific yield or drainable porosity for water table conditions in an aquifer.
- Discharge (Q) - The rate of flow in gallons per minute (gpm).

1 cubic foot per sec. (cfs)	=	449	gpm
1 barrel	=	42	gallons
1 barrel per hour (bph)	=	0.70	gpm
1 gallon per min. (gpm)	=	1.43	bph

- Drawdown (s) - The decrease in the static head of water of the aquifer due to pumping (ft.).
- Hydraulic Conductivity (K) - The rate of flow in gallons per day through a one square foot cross-sectional area of the aquifer under a hydraulic gradient of one foot per foot (gpd/ft.2).
- Perched aquifer - an aquifer separated from an underlying aquifer by unsaturated rock.
- Specific Capacity (SC) - The discharge from the testhole divided by the drawdown (gpm/ft.).
- Static Water Level (SWL) - The depth of the water level measured from ground level in a well or monitoring hole.
- Transmissivity (T) - The rate of flow in gallons per day through a vertical strip of the aquifer one foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of one foot per one foot (gpd/ft.). The transmissivity equals the hydraulic conductivity times the aquifer thickness.
- Water Table Condition - The case where the water level is equal to or lower than the top of the aquifer.

A. Surface Water

1. Precipitation - The USGS has installed six rain gaging stations. Three of these stations are of the storage type gages; precipitation is

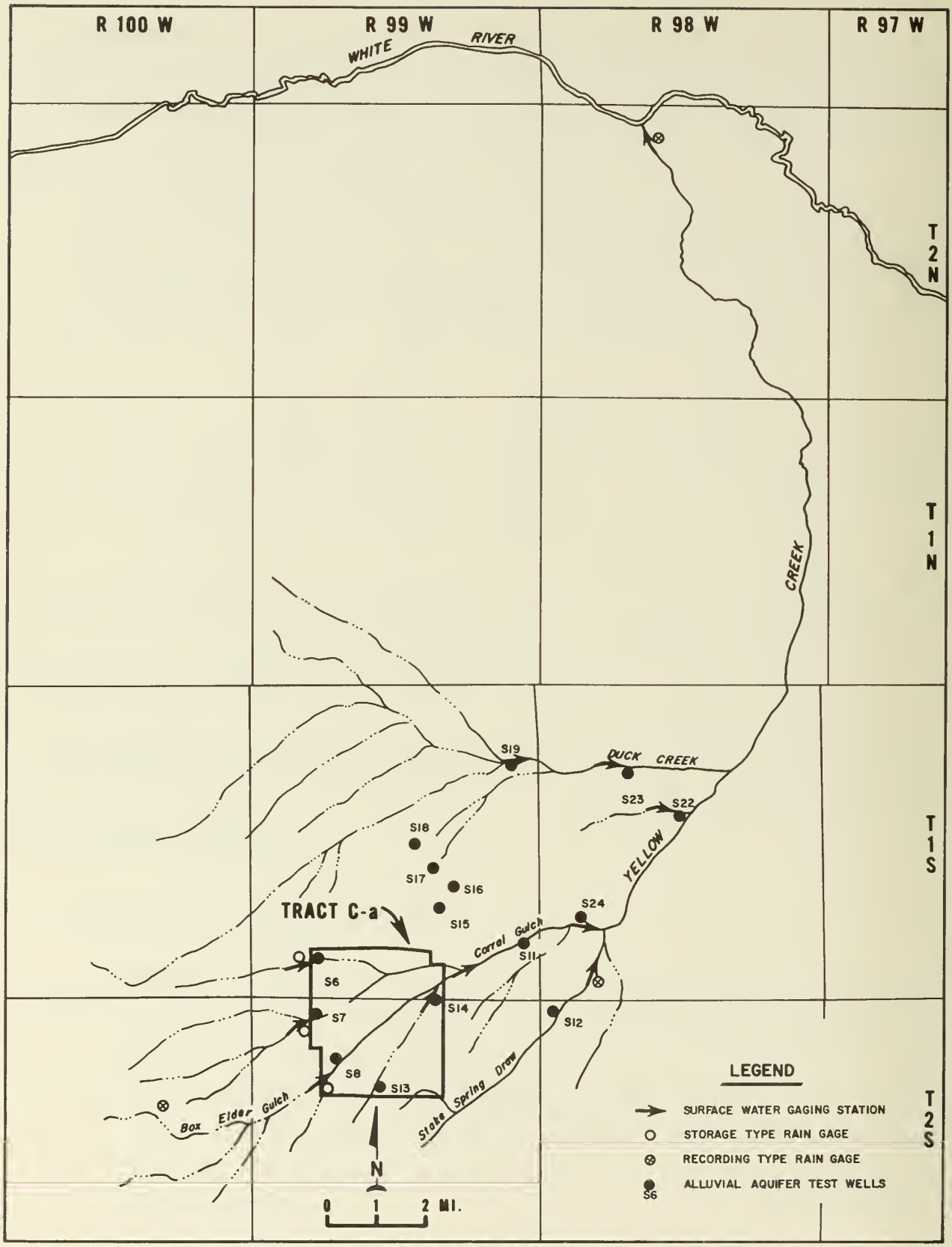


Figure 3-4-2

SURFACE WATER GAGING STATION AND ALLUVIAL MONITOR HOLE MAP

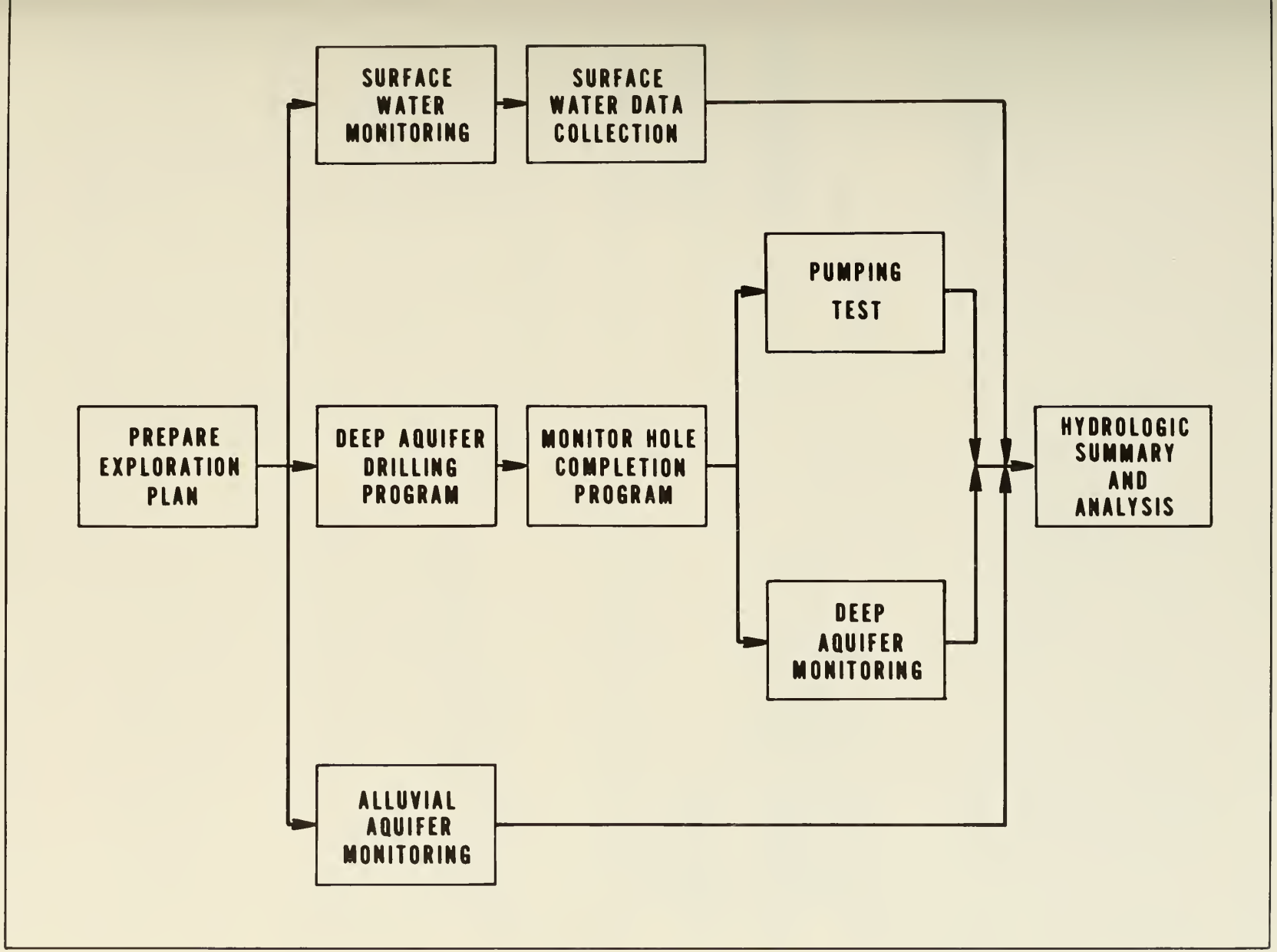


Figure 3-4-3

HYDROLOGIC PROGRAM FLOW DIAGRAM

Table 3-4-1

BASELINE MONITORING

Source	Date First Data Collected
Tract C-a	
Surface Runoff	
Water Quality Sampling	March, 1974
Continuous Temperature, Conductivity, Flow, and Automatic Sediment Collection	November, 1974
Precipitation Monitoring	September 1974
Alluvial Aquifer	
Monitoring	January, 1975
Sampling	March, 1975
Deep Aquifer Sampling and Monitoring	December, 1974
84 Mesa	
Surface Runoff	
Water Quality Sampling	April, 1975
Continuous Temperature, Conductivity, Flow, and Automatic Sediment Collection	November, 1975
Alluvial Aquifer Sampling and Monitoring	June, 1975
Deep Aquifer Sampling and Monitoring	June, 1975

collected and hand measured at regular intervals. These three are associated with the surface gaging stations at Dry Fork, Box Elder and Corral Gulch near the west boundary of the tract. The remaining three rain gages record both cumulative precipitation as well as precipitation rate, for example, inches per hour, for individual storms. One of these is located west of the tract near the drainage divide of Cathedral Bluffs. The second is located at the surface gaging station near the mouth of Yellow Creek. The third is located at the Stake Springs Draw surface gaging station shown on Figure 3-4-2. Table 3-4-2 shows the monthly average of this data for the six rain gaging stations.

Table 3-4-2

SUMMARY OF PRECIPITATION DATA FOR 1975

Storage-Type Rain Gage Locations*	Monthly (Inches) Max	Min	Avg	12-Month Total
1. Dry Fork near west line Tract C-a	1.95	0.23	0.71	8.55
2. Box Elder Gulch near west line Tract C-a	2.04	0.26	0.82	9.85
3. Corral Gulch near west line Tract C-a	2.1	0.23	0.77	9.24
Recording-Type Rain Gage Locations				
4. Stake Springs Draw near confluence with Corral Gulch	2.43	0.06	1.22	14.65
5. Yellow Creek near White River	1.91	0.04	1.01	12.10
6. Cathedral Bluffs located in NW1/4, NW1/4, Sec. 14, T2S, R100W	2.49	0.43	1.49	17.88

*Partial loss of precipitation storage by evaporation in July 1975. Precipitation for December, 1975, estimated at 1 inch.

Based on 1975's year to record, Tract C-a has received approximately 10 inches annual precipitation. The driest summer months were August and September, with less than 0.5 inch per month, and January and February, with less than 1 inch per month were the driest winter months.

The wettest months were March, May and July, each recording over 2 inches per month.

The largest single storm was recorded at the Stake Springs Draw station on July 9, 1975. During the storm, 1.06 inches of precipitation were recorded by the intensity gage and 1.19 inches by the recording gage. Generally, the recording gage is considered more accurate than the sum of the intensity readings for total storm precipitation. The maximum intensity was 0.51 inches recorded in a 45-minute period. The same storm resulted in a total of 0.36 inches of precipitation at the Cathedral Bluffs station.

2. Springs and Seeps - Thirty-seven springs and seeps have been inventoried in the Tract C-a area. Some of these are intermittent, i.e., have seasonally dependent flows. More than 50% of the springs and seeps inventoried have perennial flows based on observations during the past 18 months. Figure 3-4-4 shows the locations of these springs and seeps. The source of these flows can have several origins, some of which are:

alluvial aquifers
perched aquifers
upper oil shale aquifers
lower oil shale aquifers

Springs emitting from each of these sources could have unique identifiable properties. However, a careful investigation of the work being done by the State Engineer's Office, USGS and NUS does not reveal any conclusive data.

3. Streams - In order to establish an environmental baseline for the surface hydrology, the Rio Blanco Oil Shale Project has contracted with the Colorado River Water Conservation District to have the Water Resources Division (WRD) of the U. S. Geological Survey (USGS) build and operate the surface gaging stations. Table 3-4-3 gives the location and USGS station number for each station. Six gaging stations have been continuously monitoring water flow since March, 1974. Specific conductance and temperature were monitored periodically from March, 1974, to November, 1974, at which time continuous

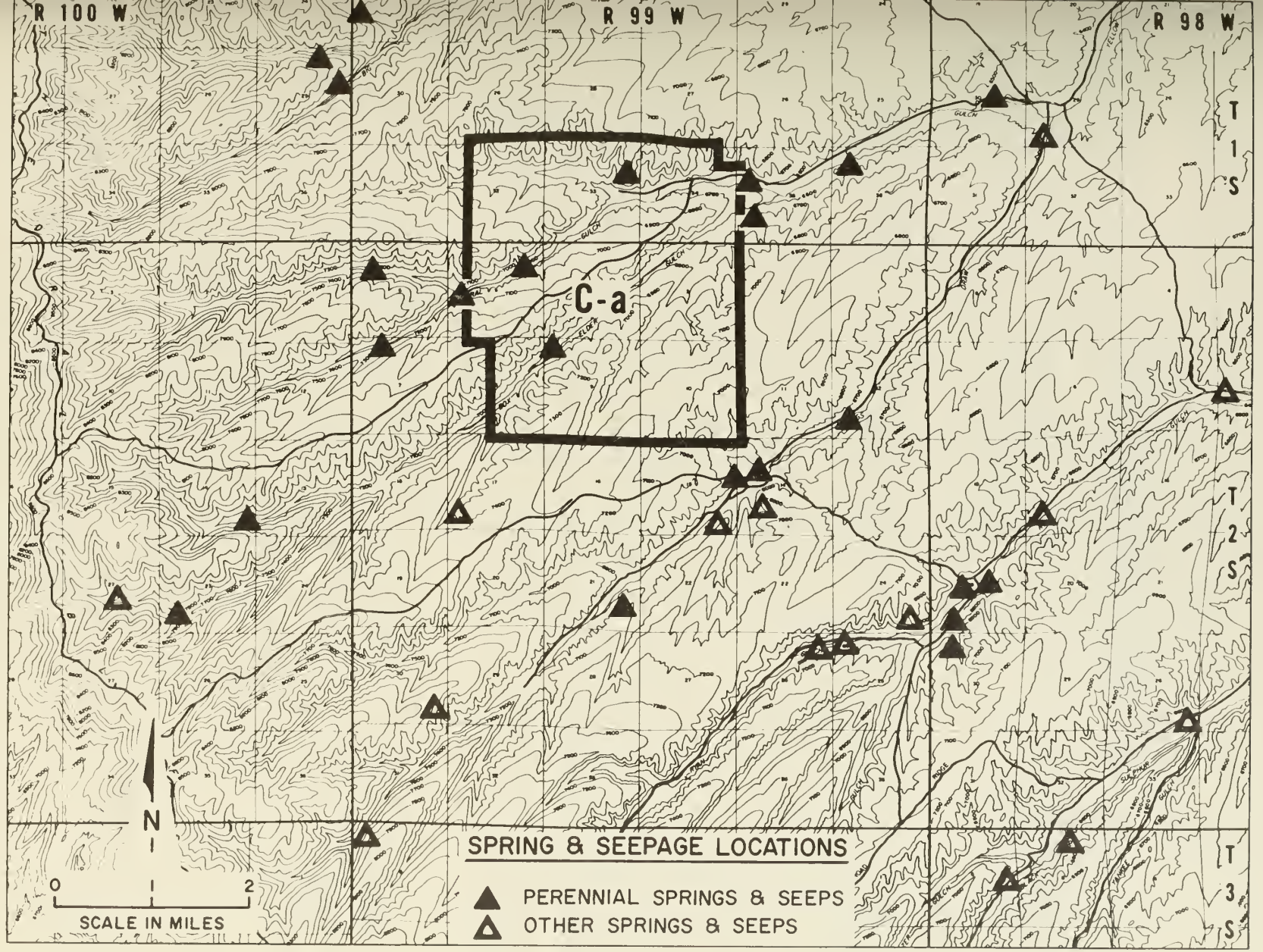


Figure 3-4-4

SPRING AND SEEP INVENTORY

Table 3-4-3

LOCATION AND USGS IDENTIFICATION NUMBERS
FOR STREAM AND RAIN GAGING STATIONS
Tract C-a and Vicinity

USGS Identification Number	Location
09306237	Dry Fork near west line Tract C-a
09306235	Corral Gulch near west line Tract C-a
09306240	Box Elder Gulch near west line Tract C-a
09306242	Corral Gulch east of Tract C-a
09306230	Stake Springs Draw near confluence with Corral Gulch
09306255	Yellow Creek near White River, Colorado
09306241	"Rinky Dink"Gulch near east line Tract C-a
09306248	Upper Big Duck Creek north of 84 Mesa
09306250	Lower Big Duck Creek north of 84 Mesa
09306246	Tributary to Yellow Creek east of 84 Mesa
09306244	Corral Gulch near 84 Ranch
	Rain Storage-Type Gages
09306235	Corral Gulch near west line Tract C-a
09306237	Dry Fork near west line Tract C-a
09306240	Box Elder Gulch near west line Tract C-a
	Recording Rain Gage
09306230	Stake Springs Draw near confluence with Corral Gulch
09306255	Yellow Creek near White River, Colorado
No number	Cathedral Bluffs located in NW 1/4, NW 1/4, Sec. 14, T2S, R100W

monitoring equipment for specific conductance and temperature was installed in the six stations. The seventh gaging station, located at the mouth of "Rinky Dink" Gulch, has been recording water flow data since November, 1974.

To establish a baseline for the 84 Mesa area, four additional surface gaging stations have been completed. Observations have been made since April, 1975. The first flow was observed in June at which time samples were collected. The equipping of these stations was completed in October, 1975. Figure 3-4-2 shows the location of the 11 surface gaging stations.

The stations consist of a control and weir built across the stream for measuring water flow rates. In addition to the flow rate, temperature and conductivity is continuously monitored by the use of automatic recording equipment. At periodic intervals, water samples are collected and analyses are run for various chemical constituents as outlined by the Area Oil Shale Supervisor.

Automatic sediment samplers have been installed in order to collect data on the sediment load of the stream. Where there are relatively steady stream flows, the samplers are programmed to take samples at regular intervals. In the case where there are intermittent stream flows, the samplers are programmed to collect sediment samples every 2 minutes during a runoff event. Therefore, good data should be obtained for the flash flood situation showing the sediment load at various stream stages.

No flow has been noted during the monitoring period at the Dry Fork, Rinky Dink Gulch, Stake Springs Draw, Upper Big Duck Creek or tributary to Yellow Creek gaging stations. The Box Elder Gulch and Lower Duck Creek gaging stations have recorded flow only during spring snowmelt or thunderstorm periods. The remaining three stations have some perennial flow; however, the flow is quite variable depending on the time of the year. Table 3-4-4 indicates the minimum, maximum, and average flow, specific conductance, temperature and sediment discharge at each of the gaging stations. The above mentioned table and averages are for the 1975 water year beginning October 1, 1974, and ending September 30, 1975.

Table 3-4-4

WATER YEAR 1975 (10/1/74 THRU 9/30/75)

Station	Constituent	Maximum Value	Minimum Value	Average Value
Corral Gulch Near West Line Tract C-a	Conductivity (Micromhos/cm)	1630	772	1100
	Temperature (^{O}C)	39.4	0	*
	Flow (C.F.S.)	.47	.01	.15
	Sediment Discharge (tons/day)	*	*	*
Box Elder Gulch Near West Line Tract C-a	Conductivity (Micromhos/cm)	2150	583	821
	Temperature (^{O}C)	31.4	.4	11.0
	Flow (C.F.S.)	2.9	.01	*
	Sediment Discharge (tons/day)	21	.01	.72
Corral Gulch East of Tract C-a	Conductivity (Micromhos/cm)	2230	1000	1200
	Temperature (^{O}C)	24.9	1.5	10.0
	Flow (C.F.S.)	5.0	.34	.87
	Sediment Discharge (tons/day)	56.0	.01	2.36
Yellow Creek Near White River, Colorado	Conductivity (Micromhos/cm)	5900	1540	3200
	Temperature (^{O}C)	44.6	.4	12.0
	Flow (C.F.S.)	2.5	.66	1.8
	Sediment Discharge (tons/day)	83	.10	2.55

*Values Not Available

During 1974 and the first half of 1975, water samples were collected every two weeks and were analyzed for approximately 50 chemical constituents. In the latter half of 1975, sampling for these constituents was done on a monthly basis. Quarterly samples were also taken and analyzed for an additional 25 items. Table 3-4-5 indicates by gaging station and month if the streams were flowing and a water sample collected. The summaries of these analyses for each of the gaging stations are given in Tables 3-4-6 and 3-4-7.

Also shown on Table 3-4-6 are the values for the chemical constituents analyzed by NUS as part of the Aquatic Biology Monitoring Program. The NUS data are discussed in Section 3, Chapter 8. The data from the USGS and NUS are in very close agreement, considering that the samples were collected at different times and that different analytical methods were used in some cases.

The important constituent to note is the dissolved solids which is an indicator of overall water quality. In the vicinity of Tract C-a, the surface water is comparably quite good, having an average dissolved solids content of 770 mg/l. In contrast, Yellow Creek near its confluence with the White River has an average dissolved solids content of 2400 mg/l. Because some of the chemical constituents exceed the limits set by the U. S. Public Health Service for drinking water standards, the water in lower Yellow Creek, by those standards, would not be considered safe for human consumption.

B. Ground Water - Three types of aquifers are present in the Piceance Creek basin. They are the alluvial, the perched and the deep bedrock aquifers. The only significant aquifers found in the vicinity of Tract C-a were the alluvial and deep bedrock aquifers.

The water-bearing zone being monitored by G-S M5 on 84 Mesa is possibly perched. Figure 3-4-5 shows the location of the aquifer monitoring holes.

1. Alluvial Aquifers - From areal photography, Trollinger Geological Associates, Inc., mapped alluvium occurrences in the vicinity of Tract C-a. In order to determine the depth, thickness and water saturation of the alluvium, an alluvial test drilling program was initiated in April 1975. The holes which contain water are being used as monitor holes.

Table 3-4-5
SURFACE GAGING STATION FLOW AND SAMPLING SUMMARY
TRACT C-a

		1974										1975											
		Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dry Fork Near West Line Tract C-a	Flow									No Flow													
	Sample																						
Corral Gulch Near West Line Tract C-a	Flow	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X		X	
	Sample	X	X	X	X	X	X	X	X	X		X			X	X	X	X	X	X		X	
Box Elder Gulch Near West Line Tract C-a	Flow		X	X	X											X	X	X	X				
	Sample		X	X												X	X						
Corral Gulch East Of Tract C-a	Flow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
	Sample	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Stake Springs Draw Near Confluence W/Corral Gulch	Flow									No Flow													
	Sample																						
Yellow Creek Near White River, Colo.	Flow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Sample			X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
"Rinky Dink" Gulch Near East Line Tract C-a	Flow									No Flow													
	Sample																						
Upper Big Duck Creek North of 84 Mesa	Flow									No Flow													
	Sample																						
Lower Big Duck Creek North of 84 Mesa	Flow																			X			
	Sample																			X			
Tributary to Yellow Creek East of 84 Mesa	Flow									No Flow													
	Sample																						
Corral Gulch South of 84 Mesa	Flow																X	X		X	X	X	
	Sample																X	X		X	X	X	

X = Indicates by month if surface flow was recorded or samples were collected

Table 3-4-6

SURFACE WATER ANALYSIS SUMMARY
OCTOBER 1, 1974 THROUGH SEPTEMBER 30, 1975
BOX ELDER GULCH NEAR WEST LINE OF TRACT C-a
(SHOWING COMPARISON OF USGS & NUS DATA)

	ITEM	USGS DATA HIGH	LOW	AVERAGE	STD DEV.	# ITEMS AVERAGED	NUS DATA HIGH	LOW	AVERAGE	STD DEV.	# ITEMS AVERAGED
1.	Alkalinity (mg/l)	290.000	257.000	272.000	13.900	4					
2.	Aluminum (ug/l)	30.000	30.000	30.000	0.000	1					
3.	Ammonia (mg/l)	0.010	0.000	0.003	0.005	4					
4.	Arsenic (ug/l)	8.000	3.000	5.250	2.060	4	0.000	0.000	0.000	0.000	2
5.	Barium (ug/l)	100.000	0.000	53.400	50.600	5					
6.	Beryllium (ug/l)	-2.000	-2.000	0.000	0.000	1					
7.	Bicarbonate (mg/l)	354.000	313.000	332.000	17.200	4					
8.	Bismuth (ug/l)	-4.000	-4.000	0.000	0.000	1					
9.	Boron (ug/l)	110.000	60.000	84.000	20.700	5					
10.	Cadmium (ug/l)	0.000	0.000	0.000	0.000	5					
11.	Carbonate (mg/l)	0.000	0.000	0.000	0.000	4					
12.	Carbon Dioxide (mg/l)	1.600	0.500	0.967	0.569	3					
13.	Chloride (mg/l)	6.000	5.200	5.600	0.462	4	6.000	6.000	6.000	0.000	2
14.	Chromium (ug/l)	20.000	0.000	4.000	8.940	5					
15.	Cobalt (ug/l)	-4.000	-4.000	0.000	0.000	1					
16.	COD	22.000	22.000	22.000	0.000	1					
17.	Coliform, Fecal										
18.	Color (PCU)	17.000	2.000	9.250	6.130	4	35.000	35.000	35.000	0.000	2
19.	Conductivity, Specific	880.000	800.000	831.000	38.800	4					
20.	Copper (ug/l)	6.000	1.000	2.800	1.920	5					
21.	Cyanide (mg/l)	0.010	0.000	0.005	0.005	4					
22.	Discharge (cfs)										
23.	Discharge, Instantaneous (cfs)	0.550	0.490	0.520	0.042	2					
24.	Dissolved Oxygen (mg/l)	8.800	5.500	7.650	1.470	4					
25.	Fluoride (mg/l)	0.400	0.300	0.325	0.050	4					
26.	Gallium (ug/l)	-2.000	-2.000	0.000	0.000	1					
27.	Germanium (ug/l)	-5.000	-5.000	0.000	0.000	1					
28.	Hardness (Ca, Mg) (mg/l)	380.000	340.000	353.000	18.900	4	410.000	400.000	405.000	7.070	2
29.	Hardness, Non-Carbonate (mg/l)	86.000	67.000	78.300	8.060	4					
30.	Iron (ug/l)	40.000	0.000	15.600	15.400	5					
31.	Kjeldahl Nitrogen (mg/l)	2.700	0.310	1.010	1.140	4					
32.	Lead (ug/l)	-4.000	1.000	1.400	1.140	5	0.000	0.000	0.000	0.000	2
33.	Lithium (ug/l)	20.000	10.000	16.000	5.480	5					
34.	Magnesium (mg/l)	47.000	44.000	46.000	1.410	4	41.000	41.000	41.000	0.000	2
35.	Manganese (ug/l)	20.000	0.000	6.000	8.216	5					
36.	Mercury (ug/l)	0.000	0.000	0.000	0.000	4	0.000	0.000	0.000	0.000	2
37.	Molybdenum (ug/l)	35.000	35.000	35.000	0.000	1					
38.	Nickel (ug/l)	-4.000	-4.000	0.000	0.000	1					
39.	Nitrate (mg/l)	1.000	0.880	0.930	0.050	4	1.100	1.000	1.050	0.071	2
40.	Nitrite (mg/l)	0.010	0.000	0.005	0.005	4	0.010	0.010	0.010	0.000	2
41.	Nitrite Plus Nitrate (mg/l)	1.000	0.890	0.935	0.047	4					
42.	Nitrogen, Ammonia (mg/l)	0.010	0.000	0.003	0.005	4	0.100	0.100	0.100	0.000	2
43.	Odor (Severity)	0.000	0.000	0.000	0.000	4					
44.	Oil & Grease (mg/l)	3.000	1.000	2.000	0.816	4					
45.	Ortho-Phosphate (mg/l)	0.090	0.030	0.053	0.029	4					
46.	Ortho-Phosphorus (mg/l)	0.030	0.010	0.018	0.009	4	0.010	0.010	0.010	0.000	2
47.	Pesticides	0.000	0.000	0.000	0.000	1					
48.	pH	9.000	8.500	8.770	0.252	3					
49.	Phosphorus, Total (mg/l)	0.410	0.030	0.148	0.180	4					
50.	Potassium (mg/l)	1.500	0.700	0.975	0.377	4	1.600	1.500	1.550	0.071	2
51.	Selenium (ug/l)	5.000	3.000	4.250	0.957	4					
52.	Silica (mg/l)	23.000	21.000	22.000	0.816	4	20.700	20.500	20.600	0.151	2
53.	Silver (ug/l)	0.000	0.000	0.000	0.000	1					
54.	Sodium (mg/l)	56.000	39.000	49.800	7.810	4	49.000	48.000	48.500	0.707	2
55.	Sodium Adsorption Ratio	1.300	0.900	1.150	0.190	4					
56.	Sodium (%)	27.000	20.000	23.800	3.300	4					
57.	Solids, Dissolved (mg/l)	527.000	482.000	513.000	20.600	4	506.000	502.000	504.000	2.830	2
58.	Solids, Dissolved T/D	0.770	0.690	0.730	0.057	2					
59.	Solids, Dissolved T/AC-Ft	0.720	0.660	0.700	0.027	4					
60.	Solids, Suspended (mg/l)	0.000	0.000	0.000	0.000	0					
61.	Strontium (ug/l)	700.000	700.000	700.000	0.000	1					
62.	Sulfate (mg/l)	170.000	140.000	155.000	12.900	4					
63.	Sulfide (mg/l)	0.200	0.000	0.100	0.115	4					
64.	Temperature (°C)	27.500	8.500	16.900	8.300	4					
65.	Tin (ug/l)	-4.000	-4.000	0.000	0.000	1					
66.	Titanium (ug/l)	-2.000	-2.000	0.000	0.000	1					
67.	Turbidity, (JTU)	210.000	13.000	76.300	90.400	4					
68.	Vanadium (ug/l)	6.000	6.000	6.000	0.000	1					
69.	Zinc (ug/l)	10.000	0.000	4.000	5.477	5					
70.	Zirconium (ug/l)	-5.000	-5.000	0.000	0.000	1					
71.	Calcium (mg/l)	75.000	57.000	64.500	7.600	4	80.000	75.000	77.500	3.540	2
72.	Radioactivity										
	Gross Alpha (pci)	0.000	0.000	0.000	0.000						
	Radium 226*										
	Gross Beta	0.000	0.000	0.000	0.000						
	Thorium 230**										
	Uranium**										
73.	Total Organic Carbon (mg/l)	11.000	11.000	11.000	0.000	1					
	Organic Carbon, Dissolved	9.000	9.000	9.000	0.000	1	11.000	9.000	10.000	1.420	2
	Organic Carbon, Suspended	0.700	0.700	0.700	0.000	1					

(-) Less than detectable limit given

Table 3-4-6 (Continued)

SURFACE WATER ANALYSIS SUMMARY
OCTOBER 1, 1974 THROUGH SEPTEMBER 30, 1975
CORRAL GULCH NEAR WEST LINE TRACT C-a
(SHOWING COMPARISON OF USGS & NUS DATA)

		USGS DATA					NUS DATA				
	ITEM	HIGH	LOW	AVERAGE	STO OEV.	# ITEMS AVERAGED	HIGH	LOW	AVERAGE	STO OEV.	# ITEMS AVERAGED
1.	Alkalinity (mg/l)	421.000	291.000	323.000	28.000	19					
2.	Aluminum (ug/l)	40.000	35.000	38.300	2.890	3					
3.	Ammonia (mg/l)	0.120	0.000	0.021	0.035	13					
4.	Arsenic (ug/l)	9.000	1.000	4.740	1.730	19	0.000	0.000	0.000	0.000	10
5.	Barium (ug/l)	200.000	0.000	31.200	57.000	22					
6.	Beryllium (ug/l)	-2.000	-1.000	0.000	0.000	3					
7.	Bicarbonate (mg/l)	513.000	355.000	394.000	34.000	19					
8.	Bismuth (ug/l)	-5.000	-5.000	0.000	0.000	3					
9.	Boron (ug/l)	130.000	60.000	94.800	17.100	22					
10.	Cadmium (ug/l)	2.000	0.000	0.182	0.501	22					
11.	Carbonate (mg/l)	0.000	0.000	0.000	0.000	13					
12.	Carbon Dioxide (mg/l)	32.000	1.200	5.990	7.110	18					
13.	Chloride (mg/l)	9.500	5.900	7.700	0.869	19	12.000	5.800	7.650	2.180	10
14.	Chromium (ug/l)	10.000	0.000	1.250	3.420	16					
15.	Cobalt (ug/l)	-5.000	-3.000	0.000	0.000	3					
16.	COD	20.000	16.000	18.000	2.830	2					
17.	Coliform, Fecal	-0.600	-0.600	0.000	0.000	1					
18.	Color (PCU)	17.000	3.000	8.620	4.680	13	35.000	2.500	16.500	11.000	10
19.	Conductivity, Specific	1200.000	900.000	1080.000	69.600	19					
20.	Copper (ug/l)	8.000	0.000	2.410	1.840	22					
21.	Cyanide (mg/l)	0.010	0.000	0.002	0.004	13					
22.	Discharge (CFS)										
23.	Discharge, Instantaneous	0.490	0.020	0.221	0.167	13					
24.	Dissolved Oxygen (mg/l)	10.200	5.600	8.610	1.480	14					
25.	Fluoride (mg/l)	0.300	0.000	0.242	0.077	19					
26.	Gallium (ug/l)	-3.000	-2.000	0.000	0.000	3					
27.	Germanium (ug/l)	-7.000	-5.000	0.000	0.000	3					
28.	Hardness (Ca, Mg) (mg/l)	510.000	390.000	448.000	29.500	19	470.000	380.000	426.000	32.200	10
29.	Hardness, Non-Carbonate (mg/l)	160.000	85.000	125.000	21.400	19					
30.	Iron (ug/l)	100.000	0.000	37.000	26.400	22					
31.	Kjeldahl Nitrogen (mg/l)	4.200	0.250	0.848	1.040	13					
32.	Lead (ug/l)	230.000	0.000	11.700	48.800	22	0.000	0.000	0.000	0.000	10
33.	Lithium (ug/l)	20.000	0.000	14.100	7.960	22					
34.	Magnesium (mg/l)	67.000	50.000	58.400	4.180	19	64.000	45.000	54.400	6.150	10
35.	Manganese (ug/l)	50.000	0.000	5.180	11.400	22					
36.	Mercury (ug/l)	1.200	0.000	0.126	0.346	19	0.000	0.000	0.000	0.000	10
37.	Molybdenum (ug/l)	50.000	45.000	47.000	2.650	3					
38.	Nickel (ug/l)	-5.000	-5.000	0.000	0.000	3					
39.	Nitrate (mg/l)	1.500	0.270	0.859	0.303	13	1.600	0.300	0.850	0.401	10
40.	Nitrite (mg/l)	0.010	0.000	0.006	0.005	13	0.010	0.010	0.010	0.000	10
41.	Nitrite Plus Nitrate (mg/l)	1.500	0.010	0.794	0.316	19					
42.	Nitrogen, Ammonia (mg/l)	0.090	0.000	0.016	0.026	13	0.100	0.100	0.100	0.000	10
43.	Odor (Severity)	1.000	0.000	0.067	0.258	15					
44.	Oil & Grease (mg/l)	9.000	0.000	2.080	2.540	12					
45.	Ortho-Phosphate (mg/l)	0.060	0.000	0.024	0.026	19					
46.	Ortho-Phosphorus (mg/l)	0.020	0.000	0.008	0.008	19	0.020	- 0.010	0.011	0.003	10
47.	Pesticides										
48.	pH	8.700	7.300	8.170	0.334	18					
49.	Phosphorus, Total (mg/l)	1.300	0.010	0.160	0.346	13					
50.	Potassium (mg/l)	1.600	0.600	1.290	0.309	19	2.500	1.500	2.040	0.327	10
51.	Selenium (ug/l)	6.000	3.000	3.840	0.900	19					
52.	Silica (mg/l)	23.000	0.200	19.700	4.930	19	21.200	18.600	19.700	1.0500	10
53.	Silver (ug/l)	0.000	0.000	0.000	0.000	3					
54.	Sodium (mg/l)	120.000	49.000	86.400	12.400	19	92.000	72.000	84.800	7.000	10
55.	Sodium Adsorption Ratio	2.300	1.000	1.770	0.252	19					
56.	Sodium (%)	34.000	19.000	29.400	3.220	19					
57.	Solids, Dissolved (mg/l)	874.000	663.000	733.000	43.200	19	749.000	643.000	702.000	35.300	10
58.	Solids, Dissolved T/D	0.990	0.040	0.444	0.342	13					
59.	Solids, Dissolved T/AC-Ft	1.190	0.900	0.997	0.059	19					
60.	Solids, Suspended (mg/l)	82.000	82.000	82.000	0.000	1					
61.	Strontium (ug/l)	1400.000	1200.000	1300.000	100.000	3					
62.	Sulfate (mg/l)	310.000	240.000	278.000	26.100	19					
63.	Sulfide (mg/l)	0.300	0.000	0.085	0.107	13					
64.	Temperature (^{o}C)	26.500	2.000	14.500	7.000	19					
65.	Tin (ug/l)	-7.000	-5.000	0.000	0.000	3					
66.	Titanium (ug/l)	-3.000	-3.000	0.000	0.000	3					
67.	Turbidity, (JTU)	450.000	2.000	64.200	120.000	13					
68.	Vanadium (ug/l)	7.000	-3.000	2.330	4.040	3					
69.	Zinc (ug/l)	410.000	0.000	35.700	87.700	22					
70.	Zirconium (uf/l)	-10.000	-7.000	0.000	0.000	3					
71.	Calcium (mg/l)	93.000	68.000	83.200	6.950	19	88.000	68.000	80.000	7.350	10
72.	Radioactivity										
	Gross Alpha (pci)	-8.900	-8.900	0.000	0.000	1					
	Radium 226*										
	Gross Beta	26.000	26.000	26.000	0.000	1					
	Thorium 230**										
	Uranium**										
73.	Total Organic Carbon (mg/l)	44.000	8.000	26.000	25.500	2					
	Organic Carbon, Dissolved	12.000	12.000	12.000	0.000	1	16.000	1.000	9.500	5.680	10
	Organic Carbon, Suspended	1.200	1.200	1.200	0.000	1					

(-) Less than detectable limit given

Table 3-4-6 (Continued)

SURFACE WATER ANALYSIS SUMMARY
OCTOBER 1, 1974 THROUGH SEPTEMBER 30, 1975
CORRAL GULCH EAST OF TRACT C-a
(SHOWING COMPARISON OF USGS & NUS DATA)

		USGS DATA					NUS DATA				
	ITEM	HIGH	LOW	AVERAGE	STO DEV.	# ITEMS AVERAGED	LOW	HIGH	AVERAGE	STO DEV.	# ITEMS AVERAGED
1.	Alkalinity (mg/l)	739.000	349.000	432.000	94.400	25					
2.	Aluminum (ug/l)	40.000	20.000	30.000	10.000	3					
3.	Ammonia (mg/l)	0.350	0.000	0.059	0.101	18					
4.	Arsenic (ug/l)	9.000	1.000	4.900	1.970	25	0.000	0.000	0.000	0.000	12
5.	Barium (ug/l)	-200.000	0.000	25.400	40.900	26					
6.	Beryllium (ug/l)	-2.000	-2.000	0.000	0.000	3					
7.	Bicarbonate (mg/l)	901.000	426.000	527.000	115.000	25					
8.	Bismuth (ug/l)	-6.000	-5.000	0.000	0.000	3					
9.	Boron (ug/l)	670.000	60.000	169.000	134.000	26					
10.	Cadmium (ug/l)	-60.000	0.000	0.346	0.689	26					
11.	Carbonate (mg/l)	0.000	0.000	0.000	0.000	19					
12.	Carbon Dioxide (mg/l)	65.000	0.900	12.600	12.000	25					
13.	Chloride (mg/l)	16.000	8.100	10.200	1.900	25	8.000	25.000	11.520	4.500	12
14.	Chromium (ug/l)	50.000	0.000	4.000	11.400	20					
15.	Cobalt (ug/l)	-6.000	-3.000	0.000	0.000	3					
16.	COD	94.000	9.000	36.500	39.700	4					
17.	Coliform, Fecal	1.000	-0.400	0.433	0.751	3					
18.	Color (PCU)	17.000	0.000	5.900	3.900	19	2.500	25.000	12.500	8.260	12
19.	Conductivity, Specific	1730.000	1000.000	1260.000	154.000	25					
20.	Copper (ug/l)	13.000	0.000	2.700	3.480	26					
21.	Cyanide (mg/l)	0.020	0.000	0.004	0.007	19					
22.	Discharge (CFS)										
23.	Discharge, Instantaneous	3.100	0.320	0.817	0.662	19					
24.	Dissolved Oxygen (mg/l)	13.000	4.800	8.600	2.100	24					
25.	Fluoride (mg/l)	10.000	0.300	1.060	2.070	25					
26.	Gallium (ug/l)	-3.000	-2.000	0.000	0.000	3					
27.	Germanium (ug/l)	-6.000	-6.000	0.000	0.000	3					
28.	Hardness (Ca, Mg) (mg/l)	520.000	360.000	462.000	44.300	25	360.000	508.000	430.000	50.900	12
29.	Hardness, Non-Carbonate (mg/l)	130.000	0.000	63.500	33.700	25					
30.	Iron (ug/l)	140.000	0.000	36.000	36.000	26					
31.	Kjeldahl Nitrogen (mg/l)	2.400	0.140	0.599	0.641	19					
32.	Lead (ug/l)	8.000	0.000	2.000	2.150	26	0.000	0.000	0.000	0.000	12
33.	Lithium (ug/l)	30.000	0.000	11.300	9.100	26					
34.	Magnesium (mg/l)	71.000	52.000	62.000	5.940	25	43.000	67.000	56.400	7.000	12
35.	Manganese (ug/l)	70.000	0.000	22.100	18.500	26					
36.	Mercury (ug/l)	0.500	0.000	0.040	0.115	25	0.000	0.000	0.000	0.000	12
37.	Molybdenum (ug/l)	56.000	26.000	37.300	16.300	3					
38.	Nickel (ug/l)	-6.000	-4.000	0.000	0.000	3					
39.	Nitrate (mg/l)	0.680	0.250	0.351	0.134	19	0.200	1.000	0.467	0.293	12
40.	Nitrite (mg/l)	0.030	0.000	0.007	0.008	19	0.010	0.020	0.011	0.003	12
41.	Nitrite Plus Nitrate (mg/l)	0.690	0.020	0.346	0.138	25					
42.	Nitrogen, Ammonia (mg/l)	0.270	0.000	0.053	0.081	19	0.010	0.100	0.093	0.026	12
43.	Odor (severity)	3.000	0.000	0.348	0.832	23					
44.	Oil & Grease (mg/l)	10.000	0.000	2.900	2.700	19					
45.	Ortho-Phosphate (mg/l)	0.280	0.000	0.086	0.059	25					
46.	Ortho-Phosphorus (mg/l)	0.090	0.000	0.028	0.019	25	0.010	0.040	0.028	0.010	12
47.	Pesticides	0.000	0.000	0.000	0.000	4					
48.	pH	9.000	7.100	8.000	0.334	25					
49.	Phosphorus, Total (mg/l)	0.600	0.000	0.157	0.217	19					
50.	Potassium (mg/l)	2.300	0.800	1.600	0.407	25	1.900	4.400	2.780	0.813	12
51.	Selenium (ug/l)	5.000	1.000	2.670	0.936	24					
52.	Silica (mg/l)	23.000	13.000	20.400	2.330	25	9.200	21.400	16.900	4.900	12
53.	Silver (ug/l)	0.000	0.000	0.000	0.000	3					
54.	Sodium (mg/l)	300.000	94.000	131.000	51.000	25	110.000	350.000	170.000	92.000	12
55.	Sodium Adsorption Ratio	6.800	2.000	3.000	1.230	25					
56.	Sodium (%)	64.000	32.000	37.500	8.700	25					
57.	Solids, Dissolved (mg/l)	1140.000	691.000	844.000	90.400	24	777.000	1200.000	901.000	150.000	12
58.	Solids, Dissolved T/D)	3.730	0.710	1.600	0.957	18					
59.	Solids, Dissolved T/AC-Ft	1.550	0.940	1.150	0.123	24					
60.	Solids, Suspended (mg/l)	2.000	-1.000	1.000	1.000	3					
61.	Strontium (ug/l)	2000.000	1400.000	1670.000	305.000	3					
62.	Sulfate (mg/l)	320.000	200.000	280.000	34.000	25					
63.	Sulfide (mg/l)	0.800	0.000	0.137	0.189	19					
64.	Temperature (^{0}C)	19.000	6.000	11.200	3.550	25					
65.	Tin (ug/l)	-6.000	-5.000	0.000	0.000	3					
66.	Titanium (ug/l)	-4.000	-3.000	0.000	0.000	3					
67.	Turbidity (JTU)	1000.000	0.000	113.000	273.000	19					
68.	Vanadium (ug/l)	4.000	3.000	3.670	0.577	3					
69.	Zinc (ug/l)	100.000	0.000	17.600	24.400	26					
70.	Zirconium (ug/l)	-12.000	-9.000	0.000	0.000	3					
71.	Calcium (mg/l)	92.000	55.000	82.300	9.600	25	54.000	88.000	73.300	12.500	12
72.	Radioactivity										
	Gross Alpha (pci)*	-12.000	-6.700	0.000	0.000	3					
	Radium 226*										
	Gross Beta	7.500	-2.400	2.500	4.330	3					
	Thorium 230**										
	Uranium**										
73.	Total Organic Carbon (mg/l)	15.000	9.800	11.600	2.950	3					
	Organic Carbon, Dissolved	9.700	9.700	9.700	0.000	1	1.000	49.000	21.000	16.700	12
	Organic Carbon, Suspended	8.700	8.700	8.700	0.000	1					

(-) Less than detectable limit given

Table 3-4-6(Continued)

SURFACE WATER ANALYSIS SUMMARY
OCTOBER 1, 1974 THROUGH SEPTEMBER 30, 1975
YELLOW CREEK NEAR THE WHITE RIVER
(SHOWING COMPARISON OF USGS & NUS DATA)

		USGS DATA					NUS DATA				
	ITEM	HIGH	LOW	AVERAGE	STD DEV.	# ITEMS AVERAGED	HIGH	LOW	AVERAGE	STD DEV.	# ITEMS AVERAGED
1.	Alkalinity (mg/l)	1580.000	1170.000	1400.000	129.000	22					
2.	Aluminum (ug/l)	150.000	70.000	96.300	36.800	4					
3.	Ammonia (mg/l)	0.520	0.000	0.153	0.169	21					
4.	Arsenic (ug/l)	9.000	0.000	4.480	1.990	21	0.000	0.000	0.000	0.000	12
5.	Barium (ug/l)	400.000	0.000	180.000	134.000	23					
6.	Beryllium (ug/l)	-8.000	-4.000	0.000	0.000	4					
7.	Bicarbonate (mg/l)	1930.000	596.000	1470.000	289.000	22					
8.	Bismuth (ug/l)	-20.000	-15.000	0.000	0.000	4					
9.	Boron (ug/l)	880.000	230.000	642.000	139.000	23					
10.	Cadmium (ug/l)	-170.000	0.000	0.565	0.662	23					
11.	Carbonate (mg/l)	657.000	0.000	118.000	146.000	22					
12.	Carbon Dioxide (mg/l)	24.000	0.200	7.720	5.210	21					
13.	Chloride (mg/l)	150.000	100.000	124.000	14.400	22	169.000	96.000	126.000	24.900	12
14.	Chromium (ug/l)	80.000	0.000	4.350	16.700	23					
15.	Cobalt (ug/l)	-20.000	-10.000	0.000	0.000	4					
16.	COD	30.000	7.000	20.800	9.800	4					
17.	Coliform, Fecal	3.800	3.800	3.800	0.000	1					
18.	Color (PCU)	45.000	2.000	13.800	11.900	21	35.000	2.500	18.300	12.000	12
19.	Conductivity, Specific	4200.000	3000.000	3600.000	373.000	22					
20.	Copper (ug/l)	7.000	0.000	2.900	2.180	23					
21.	Cyanide (mg/l)	0.000	0.000	0.000	0.000	20					
22.	Discharge (cfs)										
23.	Discharge, Instantaneous (cfs)	3.380	0.760	1.890	0.713	15					
24.	Dissolved Oxygen (mg/l)	12.200	7.400	9.790	1.430	21					
25.	Fluoride (mg/l)	2.500	1.200	2.090	0.299	22					
26.	Gallium (ug/l)	-10.000	-5.000	0.000	0.000	4					
27.	Germanium (ug/l)	-26.000	-20.000	0.000	0.000	4					
28.	Hardness (Ca, Mg) (mg/l)	650.000	440.000	541.000	51.400	22	590.000	422.000	486.000	56.700	12
29.	Hardness, Non-Carbonate (mg/l)	0.000	0.000	0.000	0.000	22					
30.	Iron (ug/l)	660.000	-8.000	59.800	133.000	24					
31.	Kjeldahl Nitrogen (mg/l)	2.600	0.170	0.823	0.514	20					
32.	Lead ug/l)	-20.000	0.000	1.960	2.310	23	0.000	0.000	0.000	0.000	12
33.	Lithium (ug/l)	180.000	120.000	147.000	19.400	23					
34.	Magnesium (mg/l)	130.000	96.000	112.000	10.800	22	126.000	95.000	107.000	9.640	12
35.	Manganese (ug/l)	50.000	0.000	15.900	15.500	24					
36.	Mercury (ug/l)	0.900	0.000	0.071	0.205	21	0.000	0.000	0.000	0.000	12
37.	Molybdenum (ug/l)	75.000	16.000	44.000	26.200	4					
38.	Nickel (ug/l)	-20.000	-10.000	0.000	0.000	4					
39.	Nitrate (mg/l)	2.700	0.010	1.200	0.830	20	2.300	0.200	0.825	0.804	12
40.	Nitrite (mg/l)	0.070	0.000	0.021	0.020	20	0.010	0.010	0.010	0.000	12
41.	Nitrite Plus Nitrate (mg/l)	2.700	0.010	1.270	0.812	22					
42.	Nitrogen, Ammonia (mg/l)	0.400	0.000	0.119	0.131	21	0.170	0.100	0.110	0.024	12
43.	Odor (Severity)	3.000	0.000	0.350	0.875	20					
44.	Oil & Grease (mg/l)	17.000	0.000	2.950	4.240	19					
45.	Ortho-Phosphate (mg/l)	0.370	0.000	0.132	0.131	22					
46.	Ortho-Phosphorus (mg/l)	0.120	0.000	0.043	0.042	22	0.050	0.010	0.017	0.016	12
47.	Pesticides	0.000	0.000	0.000	0.000	0					
48.	pH	10.100	8.100	8.680	0.437	21					
49.	Phosphorus, Total (mg/l)	0.790	0.000	0.120	0.172	20					
50.	Potassium (mg/l)	7.400	3.500	4.290	0.900	22	7.400	5.000	6.430	0.790	12
51.	Selenium (ug/l)	3.000	0.000	2.100	0.889	21					
52.	Silica (mg/l)	20.000	0.300	10.500	5.780	22	16.000	0.086	7.050	5.860	12
53.	Silver (ug/l)	-2.000	-2.000	0.000	0.000	4					
54.	Sodium (mg/l)	840.000	610.000	746.000	63.700	22	880.000	640.000	782.000	90.100	12
55.	Sodium Adsorption Ratio	17.000	11.000	13.900	1.510	22					
56.	Sodium (%)	80.000	70.000	74.800	2.470	22					
57.	Solids, Dissolved (mg/l)	2740.000	2090.000	2430.000	152.000	22	2600.000	2100.000	2390.000	155.000	12
58.	Solids, Dissolved T/D	25.000	5.190	12.600	5.040	15					
59.	Solids, Dissolved T/AC-Ft	3.730	2.840	3.310	0.207	22					
60.	Solids, Suspended (mg/l)	84.000	84.000	84.000	0.000	1					
61.	Strontium (ug/l)	3600.000	3000.000	3350.000	265.000	4					
62.	Sulfate (mg/l)	640.000	470.000	550.000	45.200	22					
63.	Sulfide (mg/l)	0.500	0.000	0.114	0.139	21					
64.	Temperature (°C)	24.000	0.500	10.200	7.380	22					
65.	Tin (ug/l)	-20.000	-15.000	0.000	0.000	4					
66.	Titanium (ug/l)	-12.000	-8.000	0.000	0.000	4					
67.	Turbidity, (JTU)	400.000	3.000	97.500	118.000	21					
68.	Vanadium (ug/l)	-17.000	-8.000	0.000	0.000	4					
69.	Zinc (ug/l)	140.000	0.000	16.700	29.200	23					
70.	Zirconium (ug/l)	-40.000	-25.000	0.000	0.000	4					
71.	Calcium (mg/l)	45.000	7.000	31.900	10.900	22	42.000	12.000	21.800	11.600	12
72.	Radioactivity										
	Gross Alpha (pci)	-36.000	-30.000	0.000	0.000	2					
	Radium 226*										
	Gross Beta	8.800	8.000	8.400	0.566	2					
	Thorium 230**										
	Uranium**										
73.	Total Organic Carbon (mg/l)	29.000	4.700	14.100	10.800	4					
	Organic Carbon, Dissolved	22.000	11.000	16.500	7.780	2	98.000	1.000	33.300	32.400	12
	Organic Carbon, Suspended	0.800	0.800	0.800	0.000	1					

(-) Less than detectable limit given

Table 3-4-7

SURFACE WATER ANALYSIS SUMMARY
OCTOBER 1, 1974 THROUGH SEPTEMBER 30, 1975
(USGS DATA ONLY)

	ITEM	Lower Big Duck Creek North of 84 Mesa					Corral Gulch Near 84 Ranch				
		HIGH	LOW	AVERAGE	STO OEV.	# ITEMS AVERAGEO	HIGH	LOW	AVERAGE	STO OEV.	# ITEMS AVERAGEO
1.	Alkalinity (mg/l)	94.000	94.000	94.000	0.000	1	540.000	426.000	500.000	41.300	7
2.	Aluminum (ug/l)	0.000	0.000	0.000	0.000	0	50.000	20.000	35.000	21.200	2
3.	Ammonia (mg/l)	0.680	0.680	0.680	0.000	1	0.060	0.000	0.020	0.028	6
4.	Arsenic (ug/l)	10.000	10.000	10.000	10.000	1	7.000	3.000	4.860	1.570	7
5.	Barium (ug/l)	-200.000	-200.000	0.000	0.000	1	200.000	0.000	51.600	71.700	9
6.	Beryllium (ug/l)	0.000	0.000	0.000	0.000	0	-4.000	-2.000	0.000	0.000	2
7.	Bicarbonate (mg/l)	115.000	115.000	115.000	0.000	1	658.000	519.000	610.000	50.400	7
8.	Bismuth (ug/l)	0.000	0.000	0.000	0.000	0	-9.000	-9.000	0.000	0.000	2
9.	Boron (ug/l)	110.000	110.000	110.000	0.000	1	210.000	130.000	173.000	28.700	9
10.	Cadmium (ug/l)	0.000	0.000	0.000	0.000	1	1.000	0.000	0.333	0.500	9
11.	Carbonate (mg/l)	0.000	0.000	0.000	0.000	1	0.000	0.000	0.000	0.000	7
12.	Carbon Dioxide (mg/l)	0.500	0.500	0.500	0.000	1	33.000	2.300	9.290	10.700	7
13.	Chloride (mg/l)	12.000	12.000	12.000	0.000	1	23.000	19.000	20.300	1.500	7
14.	Chromium (ug/l)	0.000	0.000	0.000	0.000	1	10.000	0.000	3.330	5.000	9
15.	Cobalt (ug/l)	0.000	0.000	0.000	0.000	0	-9.000	-4.000	0.000	0.000	2
16.	COD	0.000	0.000	0.000	0.000	0	25.000	20.000	22.500	3.540	2
17.	Coliform, Fecal	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0
18.	Color (PCU)	110.000	110.000	110.000	0.000	1	30.000	6.000	16.300	9.340	7
19.	Conductivity, Specific	380.000	380.000	380.000	0.000	1	2000.000	980.000	1770.000	357.000	7
20.	Copper (ug/l)	17.000	17.000	17.000	0.000	1	5.000	0.000	1.890	1.620	9
21.	Cyanide (mg/l)	0.010	0.010	0.010	0.000	1	0.010	0.000	0.001	0.004	7
22.	Oischarge(cfs)										
23.	Oischarge, Instantaneous (cfs)	0.000	0.000	0.000	0.000	0	0.810	0.270	0.522	0.205	6
24.	Oissolved Oxygen (mg/l)	0.000	0.000	0.000	0.000	0	13.800	4.400	9.050	3.190	6
25.	Fluoride (mg/l)	0.200	0.200	0.200	0.000	1	0.400	0.300	0.314	0.038	7
26.	Gallium (ug/l)	0.000	0.000	0.000	0.000	0	-4.000	-4.000	0.000	0.000	2
27.	Germanium (ug/l)	0.000	0.000	0.000	0.000	0	-13.000	-9.000	0.000	0.000	2
28.	Hardness (Ca, Mg) (mg/l)	100.000	100.000	100.000	0.000	1	790.000	650.000	743.000	59.100	7
29.	Hardness, Non-Carbonate (mg/l)	6.000	6.000	6.000	0.000	1	320.000	170.000	244.000	45.800	7
30.	Iron (ug/l)	120.000	120.000	120.000	0.000	1	120.000	0.000	56.700	39.700	9
31.	Kjeldahl Nitrogen (mg/l)	18.000	18.000	18.000	0.000	1	1.600	0.410	0.726	0.426	7
32.	Lead (ug/l)	2.000	2.000	2.000	0.000	1	-9.000	0.000	1.440	2.650	9
33.	Lithium (ug/l)	10.000	10.000	10.000	0.000	1	20.000	0.000	8.890	7.820	9
34.	Magnesium (mg/l)	6.800	6.800	6.800	0.000	1	120.000	90.000	107.000	13.600	7
35.	Manganese (ug/l)	10.000	10.000	10.000	0.000	1	250.000	10.000	119.000	67.700	9
36.	Mercury (ug/l)	0.000	0.000	0.000	0.000	1	0.100	0.000	0.029	0.049	7
37.	Molybdenum (ug/l)	0.000	0.000	0.000	0.000	0	60.000	55.000	57.500	3.540	2
38.	Nickel (ug/l)	0.000	0.000	0.000	0.000	0	-9.000	-9.000	0.000	0.000	2
39.	Nitrate (mg/l)	1.900	1.900	1.900	0.000	1	1.300	0.050	0.683	0.415	6
40.	Nitrite (mg/l)	0.210	0.210	0.210	0.000	1	0.050	0.000	0.030	0.018	6
41.	Nitrite Plus Nitrate (mg/l)	2.100	2.100	2.100	0.000	1	1.300	0.050	0.710	0.417	6
42.	Nitrogen, Ammonia (mg/l)	0.530	0.530	0.530	0.000	1	0.050	0.000	0.017	0.022	6
43.	Odor (Severity)	0.000	0.000	0.000	0.000	1	0.000	0.000	0.000	0.000	6
44.	Oil & Grease (mg/l)	0.000	0.000	0.000	0.000	0	4.000	0.000	1.570	1.270	7
45.	Ortho-Phosphate (mg/l)	0.060	0.060	0.060	0.000	1	0.060	0.000	0.025	0.023	6
46.	Ortho-Phosphorus (mg/l)	0.020	0.020	0.020	0.000	1	0.020	0.000	0.008	0.007	6
47.	Pesticides	0.000	0.000	0.000	0.000	4					
48.	pH	8.600	8.600	8.600	0.000	1	8.600	7.500	8.190	0.367	7
49.	Phosphorus, Total (mg/l)	4.900	4.900	4.900	0.000	1	0.360	0.000	0.064	0.131	7
50.	Potassium (mg/l)	4.200	4.200	4.200	0.000	1	4.400	1.900	3.060	0.894	7
51.	Selenium (ug/l)	3.000	3.000	3.000	0.000	1	6.000	1.000	3.000	1.530	7
52.	Silica (mg/l)	13.000	13.000	13.000	0.000	1	21.000	15.000	18.000	2.080	7
53.	Silver (ug/l)	0.000	0.000	0.000	0.000	0	-1.000	-1.000	0.000	0.000	2
54.	Sodium (mg/l)	48.000	48.000	48.000	0.000	1	190.000	170.000	180.000	8.170	7
55.	Sodium Adsorption Ratio	2.100	2.100	2.100	0.000	1	3.000	2.600	2.860	0.140	7
56.	Sodium (%)	50.000	50.000	50.000	0.000	1	37.000	32.000	34.500	1.720	7
57.	Solids, Oissolved (mg/l)	260.000	260.000	260.000	0.000	1	1390.000	1210.000	1324.000	68.800	7
58.	Solids, Oissolved T/O	0.000	0.000	0.000	0.000	0	2,890	0.990	1.860	0.765	6
59.	Solids, Oissolved T/AC-Ft	0.350	0.350	0.350	0.000	1	1.890	1.650	1.801	0.092	7
60.	Solids, Suspended (mg/l)	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0
61.	Strontium (ug/l)	0.000	0.000	0.000	0.000	0	2500.000	2300.000	2400.000	141.000	2
62.	Sulfate (mg/l)	80.000	80.000	80.000	0.000	1	600.000	510.000	570.000	29.500	7
63.	Sulfide (mg/l)	0.000	0.000	0.000	0.000	1	0.100	0.000	0.014	0.038	7
64.	Temperature (°C)	13.000	13.000	13.000	0.000	1	23.000	10.000	16.300	4.930	7
65.	Tin (ug/l)	0.000	0.000	0.000	0.000	0	-9.000	-9.000	0.000	0.000	2
66.	Titanium (ug/l)	0.000	0.000	0.000	0.000	0	-5.000	-4.000	0.000	0.000	2
67.	Turbidity (JTU)	3400.000	3400.000	3400.000	0.000	1	20.000	0.000	5.140	6.890	7
68.	Vanadium (ug/l)	0.000	0.000	0.000	0.000	0	-9.000	-4.000	0.000	0.000	2
69.	Zinc (ug/l)	10.000	10.000	10.000	0.000	1	20.000	0.000	11.100	6.010	9
70.	Zirconium (ug/l)	0.000	0.000	0.000	0.000	0	-20.000	-13.000	0.000	0.000	2
71.	Calcium (mg/l)	29.000	29.000	29.000	0.000	1	140.000	110.000	121.000	9.000	7
72.	Radioactivity										
	Gross Alpha (pci)	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0
	Radium 226*										
	Gross Beta	0.000	0.000	0.000	0.000	0	0.000	0.000	0.000	0.000	0
	Thorium 230**										
	Uranium**										
73.	Total Organic Carbon (mg/l)	0.000	0.000	0.000	0.000	0	11.000	11.000	11.000	0.000	1
	Organic Carbon, Oissolved	0.000	0.000	0.000	0.000	0	9.400	9.400	9.400	0.000	1
	Organic Carbon, Suspended	0.000	0.000	0.000	0.000	0	0.900	0.900	0.900	0.000	1

(-) Less than detectable limit given

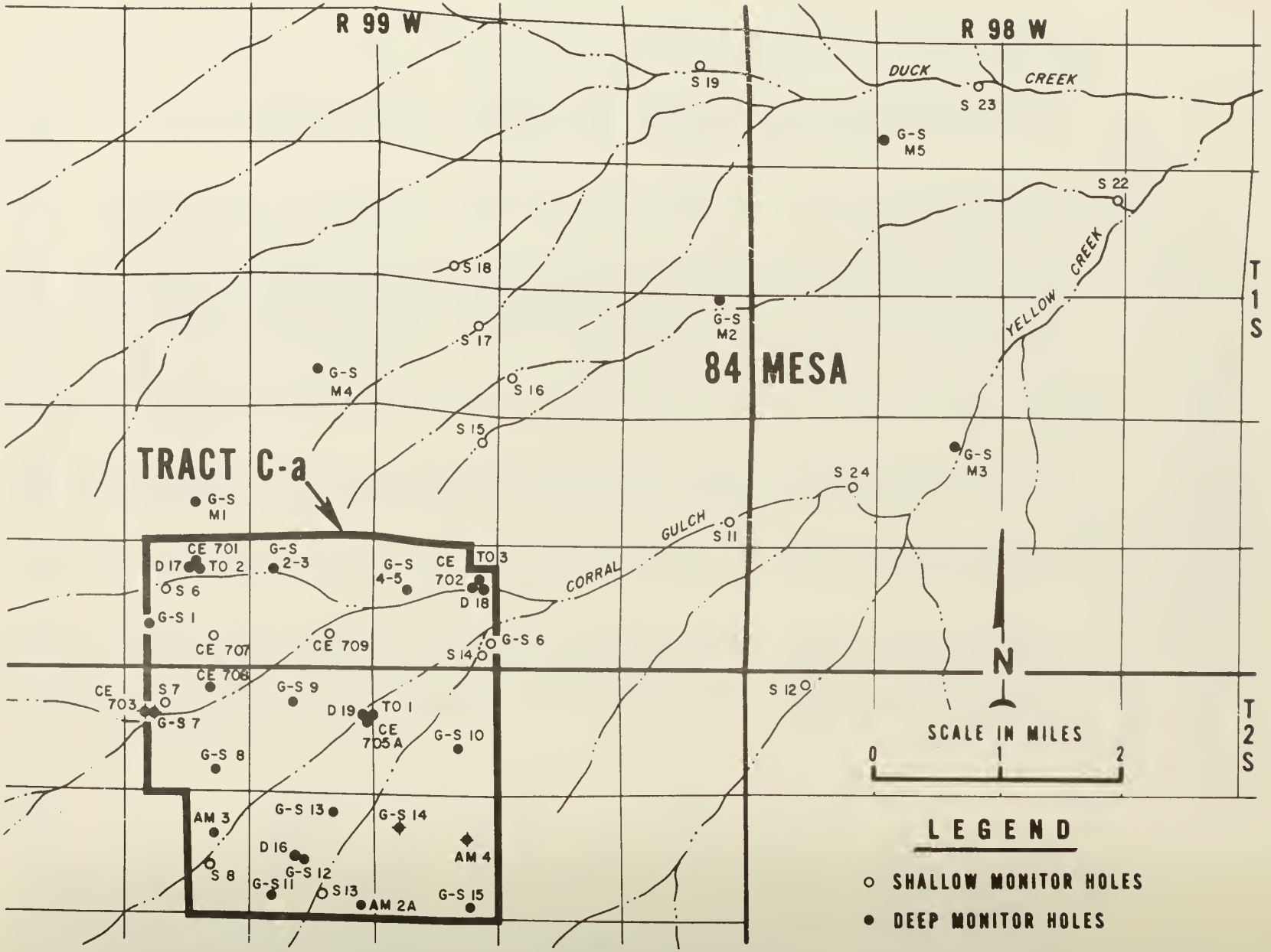


Figure 3-4-5

TRACT C-a MONITORING HOLES

A total of fifteen alluvial aquifer monitor holes, as shown on Figure 3-4-5, have been completed, all drilled to bedrock. Of these fifteen, seven did not encounter water when drilled and have remained dry throughout the monitoring period. The remaining eight encountered water during drilling and have had measurable water levels since the initial construction. Table 3-4-8 is a summary of water physical data in the eight monitor holes which encountered alluvial water.

Table 3-4-8

SUMMARY OF ALLUVIAL MONITORING HOLES
PHYSICAL DATA
Through 1975

Hole	Depth (Ft.)	SWL (Avg. Ft.)	Temp. (Avg. °C)
G-S S-7	44	22.75	9.9
G-S S-8	50	33.28	10.1
G-S S-11	66	44.88	11.0
G-S S-12	87	33.46	11.3
G-S S-19	60	54.44	11.7
G-S S-22	81	66.74	10.9
G-S S-23	83.5	29.54	10.6
G-S S-24	75	6.67	10.2

After each of the alluvial monitoring holes were drilled to bedrock, perforated PVC casing was set in each of the holes. In order to prevent contamination from the surface, five feet of seven inch casing was placed in the hole and cemented. A thread protector cap was installed on the top of the seven inch casing. Figure 3-4-6 is a typical alluvial monitor hole's cross section showing the construction and completion technique.

Each month, water samples are collected, water levels are obtained, and the pH, temperature, and conductivity are measured in the field. The samples are then sent to a commercial chemical laboratory for analysis.

Table 3-4-9 shows the constituents analyzed from the alluvial monitoring hole samples using standard chemical techniques. The low, high and average values are indicated.

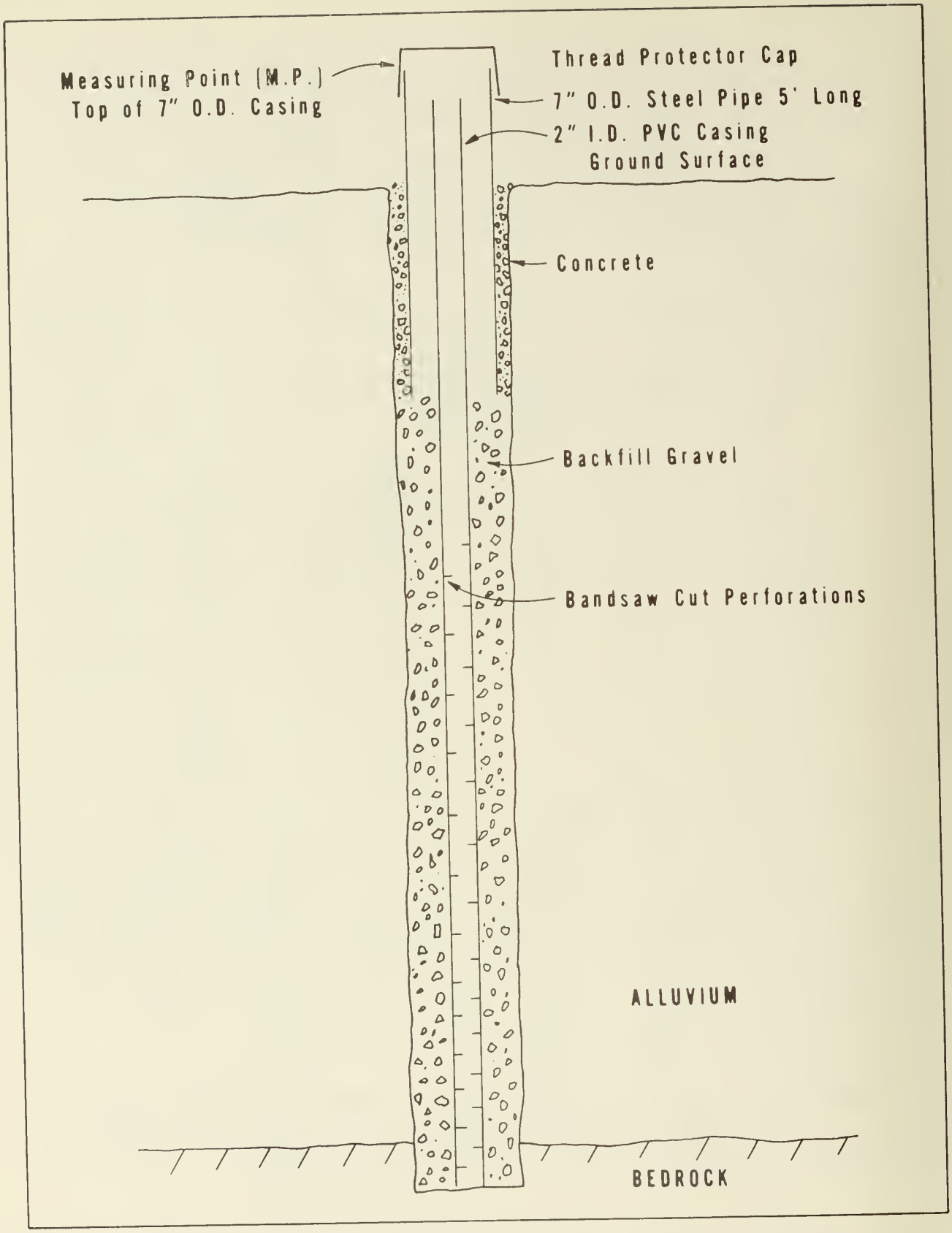


Figure 3-4-6

DIAGRAMATIC (SECTION) ALLUVIAL MONITORING HOLE

Table 3-4-9

ALLUVIAL AQUIFER WATER ANALYSIS SUMMARY (WET CHEMICAL)
MARCH 1975 THROUGH JANUARY 1976

ITEM	LOW	HIGH	AVERAGE	# ITEMS AVERAGED	STD. DEV.
Alkalinity	329.000	640.000	474.000	91	83.900
Aluminum	-0.100	-0.100	0.000	4	0.000
Ammonia	-0.100	1.700	0.337	80	0.375
Arsenic	-0.100	0.010	0.000	91	0.001
Barium	-1.000	0.300	0.003	91	0.031
Bicarbonate	370.000	780.000	573.000	91	104.000
Boron	-0.100	27.000	1.250	91	3.220
Cadmium	-0.010	1.100	0.028	91	0.122
Calcium	28.000	240.000	102.000	91	40.900
Carbonate	-0.100	605.000	11.400	91	63.900
Chloride	5.400	71.000	17.900	91	8.540
Chromium	-0.050	-0.10	0.000	90	0.000
Conductance	860.000	3400.000	1580.000	91	467.000
Copper	-0.100	8.000	0.524	91	1.250
Cyanide	-0.010	0.020	0.002	91	0.005
Dis. Solids	640.000	2880.000	1190.000	91	394.000
Fluoride	-0.100	1.200	0.367	90	0.195
Gross Alpha	1.400	31.000	12.200	87	6.960
Gross Beta	1.000	74.000	15.300	32	14.400
Hardness	280.000	820.000	600.000	91	152.000
Iron	-0.050	28.000	7.170	91	5.520
Lead	0.020	13.000	0.398	90	1.360
Magnesium	3.700	150.000	83.900	91	38.200
Manganese	-0.050	27.000	3.130	91	4.500
Mercury	-0.010	0.002	0.000	91	0.000
Nickel	0.010	0.200	0.074	91	0.058
Nitrate	-0.100	165.000	6.600	91	17.400
pH	6.000	7.200	6.490	91	0.350
Phosphate	-0.100	0.200	0.010	91	0.037
Selenium	-0.100	-0.010	0.000	91	0.000
Sil. Dioxide	7.400	44.000	31.100	91	5.570
Silver	-0.100	0.070	0.006	90	0.013
Sodium	75.000	850.000	202.000	91	108.000
Sulfate	145.000	1720.000	467.000	91	232.000
Zinc	-0.100	13.000	0.759	89	1.540

(-) Less than detectable limit given.
All values in mg/l.

The qualitative spectrographic scan includes the elements shown in Table 3-4-10. Again, the low, high and average values are indicated. The dashes indicate that either the element was not present or was below detectable limits in the sample. The term "major" indicates that the element was present in major amounts, therefore, a value could not be derived from the spectrographic scan.

The majority of the alluvial monitor holes which contained water showed water level increases during the months of May and June. The magnitude of the increase varied depending upon the drainage system in which the hole was located. During the remaining summer, fall and winter months, water levels generally decline as shown in Figure 3-4-7. This trend indicates that the majority of the recharge to the alluvial aquifer system is a result of spring snowmelt.

2. Deep Oil Shale Aquifers - As a result of the data collected from the pre-lease exploration programs, the relative location, water quality, production rates, and water temperature of the bedrock aquifers were known. In general, the upper aquifer was located in the vicinity of the Mahogany zone. The lower aquifer was known to be near the base of Parachute Creek Member, and generally includes the R-3 zone as shown in the schematic cross section Figure 3-4-8.

The water quality from the upper aquifer was found to be of better water quality than water from the lower aquifer. It was not anticipated that significant discharge problems would be expected from the discharge standards set by the AOSS for specific conductance and total dissolved solids.

a. Drilling - Several categories of hydrologic data were collected during the drilling and coring of the various holes on and around Tract C-a. These included water production, water quality, informal pump test data, and production logging information. The method and intervals at which these data were collected were based upon the AOSS stipulations and approvals of the drilling program and general knowledge from previous area investigations.

Table 3-4-10

ALLUVIAL AQUIFERS WATER ANALYSIS SUMMARY QUALITATIVE SPECTROGRAPHIC
All values in mg/l
March, 1975 through January, 1976

ITEM	LOW	HIGH	AVERAGE	# ITEMS AVERAGED	STD DEV.
Aluminum	0.005	5.000	0.402	90	0.826
Antimony	---	---	---	0	---
Arsenic	---	---	---	0	---
Barium	0.001	0.050	0.006	40	0.011
Berylium	0.001	0.001	0.001	3	0.000
Bismuth	---	---	---	0	---
Boron	0.010	0.500	0.342	90	0.185
Cadmium	---	---	---	0	---
Calcium	10.000	MAJOR	10.000	6	---
Cerium	---	---	---	0	---
Cesium	0.001	0.001	0.001	1	---
Chromium	0.000	0.010	0.003	9	0.004
Cobolt	0.001	0.001	0.001	2	0.000
Columbium	---	---	---	0	---
Copper	0.001	0.050	0.013	89	0.013
Dysprosium	---	---	---	0	---
Erbium	---	---	---	0	---
Europium	---	---	---	0	---
Gadolinium	---	---	---	0	---
Gallium	0.001	0.001	0.001	1	---
Germanium	0.001	0.001	0.001	1	---
Gold	---	---	---	0	---
Hafnium	---	---	---	0	---
Holmium	---	---	---	0	---
Indium	---	---	---	0	---
Iridium	---	---	---	0	---
Iron	0.010	2.000	0.176	90	0.397
Lanthanum	---	---	---	0	---
Lead	0.001	0.200	0.032	29	0.053
Lithium	0.001	0.100	0.007	77	0.016
Lutetium	---	---	---	0	---
Magnesium	5.000	MAJOR	2230.000	9	4410.000
Manganese	0.001	0.500	0.062	89	0.124
Mercury	---	---	---	0	---
Molybdenum	0.001	0.050	0.004	50	0.010
Neodymium	---	---	---	0	---
Nickel	0.001	0.070	0.012	6	0.028
Osmium	---	---	---	0	---
Palladium	---	---	---	0	---
Platinum	---	---	---	0	---
Potassium	0.010	2.000	0.661	90	0.479
Praseodymium	---	---	---	0	---
Radium	0.100	1.200	0.339	62	0.232
Rhenium	---	---	---	0	---
Rhodium	---	---	---	0	---
Rubidium	---	---	---	0	---
Ruthenium	---	---	---	0	---
Samarium	---	---	---	0	---
Scandium	---	---	---	0	---
Selenium	---	---	---	0	---
Silicon	2.000	20.000	5.100	90	2.850
Silver	---	0.020	0.003	28	0.005
Sodium	1.000	MAJOR	6.410	69	2.910
Strontium	0.010	0.100	0.096	87	0.019
Tantalum	---	---	---	0	---
Terbium	---	---	---	0	---
Thallium	---	---	---	0	---
Thorium	---	---	---	0	---
Thulium	---	---	---	0	---
Tin	0.001	0.001	0.001	7	0.000
Titanium	0.001	0.100	0.008	75	0.016
Tungsten	---	---	---	0	---
Uranium	---	---	---	0	---
Vanadium	0.001	0.010	0.005	8	0.005
Ytterbium	0.001	0.001	0.001	6	0.000
Yttrium	0.010	0.020	0.012	6	0.004
Zinc	0.001	0.020	0.004	37	0.005
Zirconium	---	---	---	0	---

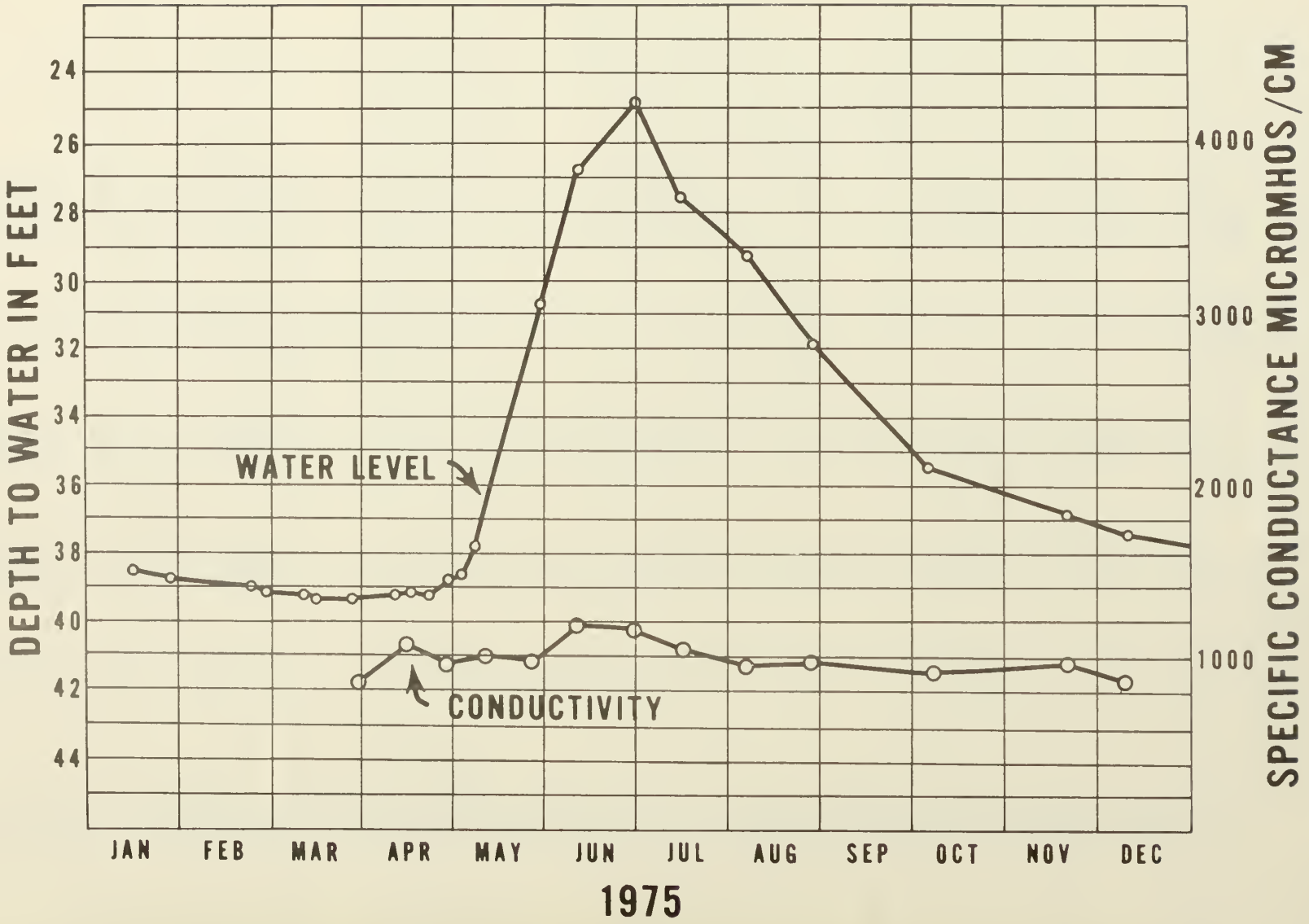


Figure 3-4-7

DEPTH TO WATER AND SPECIFIC CONDUCTANCE ALLUVIAL MONITOR
HOLE S 8

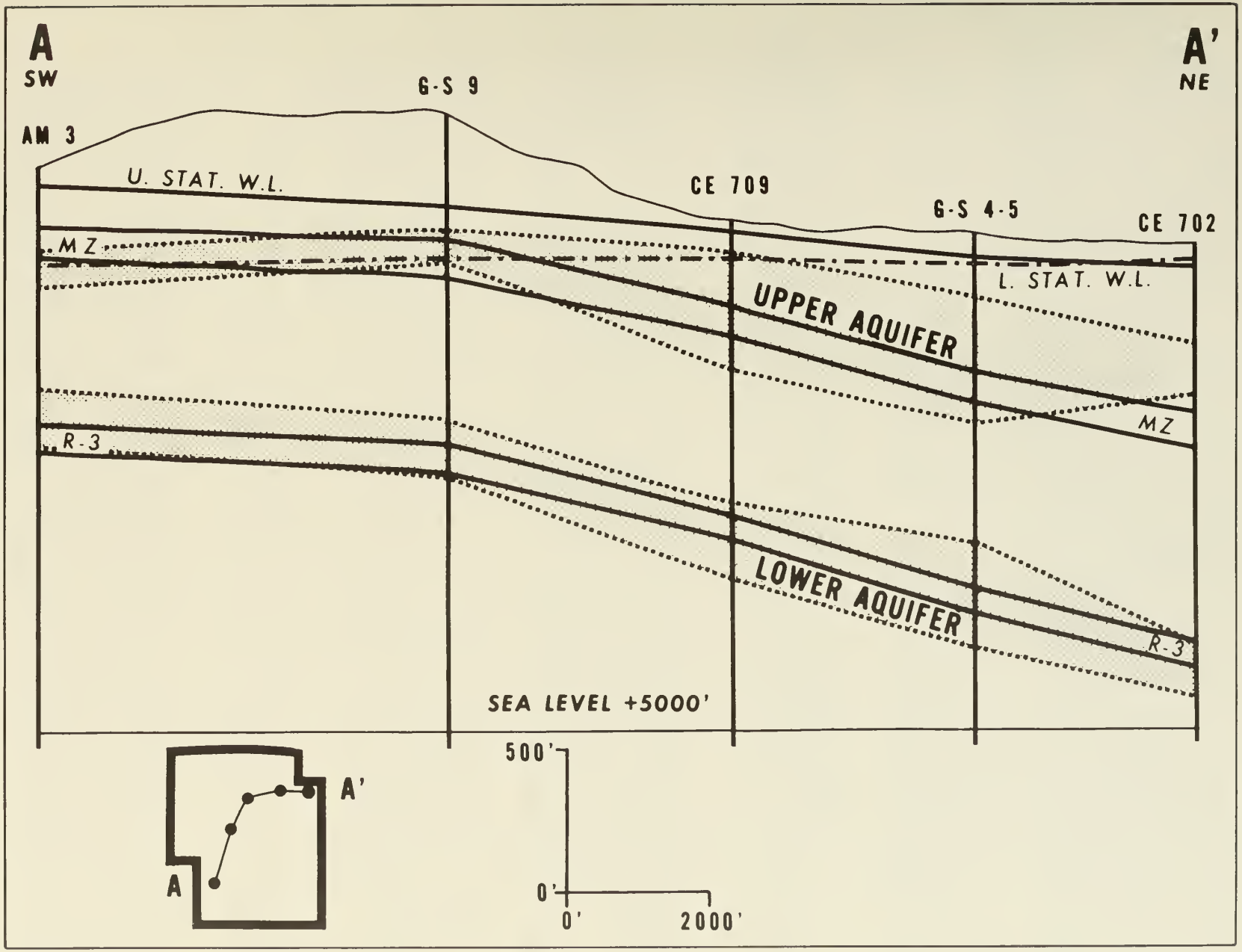


Figure 3-4-8

SW-NE CROSS SECTION SHOWING THE AQUIFER LOCATIONS

Air rotary methods of drilling are considered to be best for gathering hydrologic data during drilling in the Piceance Creek basin. Two air rotary rigs were used throughout the Gulf-Standard drilling and coring program. A mixture of water and biodegradable soapy substance was injected with the air to lubricate the bit and lift the cuttings. The coring was with a 6-3/4" x 3-1/2" diamond core bit. For the majority of the holes a 60-foot core barrel was used. Thirteen on-tract core holes, five monitor holes north and northeast of the tract, and four on-tract large diameter drill holes have been drilled by RBOSP. The location of these holes are shown on Figure 3-4-5. The drilling and coring program commenced with G-S 6 during the first week of July, 1974. This program was completed on June 30, 1975 with G-S M5.

b. Water Production - Water production was continuously monitored during drilling. Water entering the borehole from a subsurface aquifer during the course of air drilling is forced to the surface along with the cuttings. At the surface, air, water and cuttings travel through the "blooey line" to a stilling basin (steel tank) and pit which settled the cuttings. A 6" x 15" Parshall flume with a Stevens Type F recorder was installed on the outlet of the "blooey pit" to measure water production with respect to time. The production record was then referenced to the drilling depth record (geolograph) to assist in determining at what depth significant aquifers were encountered.

In general, the drilling program indicated the existence of two deep oil shale aquifers in the Tract C-a area. Competent oil shale has very little or no permeability and in itself would be a poor medium for an aquifer. However, fracturing and jointing, coupled with the leaching of the once-present saline mineral nahcolite, have created secondary permeability within the oil shales under Tract C-a. The aquifers have been delineated on the basis of water quality, water temperature, water yield and permeability.

The upper aquifer includes water-bearing zones of similar water quality and temperature characteristics and has an upper stratigraphic limit above the Mahogany zone and a lower limit as low as the top of the R-5 zone. The lower aquifer includes water-bearing zones with similar water quality and temperature characteristics and its stratigraphic limits range from the bottom of the

R-4 zone to the Blue marker. With the exception of G-S 4-5, the water flow in the bore hole after drilling was from the upper aquifer to the lower aquifer. Production from the upper aquifer varied from as little as 40 gallons per minute (gpm) to over 1,000 gpm, with an average maximum of 247 gpm. Water produced from below the top of the lower aquifer, which included production from both aquifers, varied from 150 gpm to over 1,000 gpm. The average maximum of combined production was 438 gpm.

c. Water Quality - Water quality samples were collected from the "blooey line" for standard wet chemical and spectrographic analyses, generally four times during the drilling or coring of each hole. At 30-foot depth intervals, conductivity, pH and temperature were measured. Conductivity was obtained using a standard conductivity meter. Temperature was measured with standardized mercury thermometers, and pH sensitive paper was used to measure the pH.

The conductivity for the upper aquifer ranged from less than 1,000 micromhos/centimeter to 1,700 micromhos/centimeter with an average of 1,290 micromhos/centimeter. For the combined aquifers, the range varied from 1,300 to a maximum of 20,000 micromhos/centimeter, the average was 3,940 micromhos/centimeter. The lower aquifer water is generally more alkaline than the upper aquifer water. The dissolved solids average 1,160 milligrams/liter for the upper aquifer and 2,370 milligrams/liter for combined aquifer water. The average water temperature from the upper aquifer varied from 54°F to 60°F, averaging 58°F while the combined aquifer water temperature ranged from 59°F to 79°F.

The first sample was taken at a depth where the first significant water production from the bore hole occurred. This could be considered near the top of the upper aquifer. The second sample was taken in the vicinity of the B-groove. This sample should represent the water in the upper aquifer. The third sample was taken at the first significant change in water production and water quality below the B-groove. Generally, this sample is collected in the vicinity of the R-3 zone and could be considered the top of the lower aquifer. This sample would represent a mixture of waters from the upper aquifer and the

upper portion of the lower aquifer. The fourth sample (also a mixture of waters from both the upper and lower aquifers), was collected after the hole reached total depth. This fourth sample was also found to be generally of the poorest water quality.

In addition to the above four samples collected from each hole, a water sample was collected at 200-foot intervals during the drilling, as required by the AOSS. These samples are presently being stored at the office of Wright-Water Engineers, Inc.

The drilling of monitor holes G-S M2 and G-S M3 was discontinued when the conductivity exceeded 5,000 micromhos/cm. several hundred feet short of the anticipated total depth. In consideration of the environment and economics, it would not have been practical to dig pits of sufficient size to contain the water precluding its discharge into the stream beds.

d. Informal Pumping Tests - Informal pumping tests were conducted during drilling in order to generally define aquifer properties, such as the transmissivity and the specific capacity. An informal pump test consists of forcing the inflowing water out of the bore hole by injecting air under pressure through the open drill pipe. These tests were conducted when the hole had been drilled to a depth just below the B-groove and at total depth. The "pumping" was continued for two hours (with consequential water level drawdown), during which time water production was monitored. The air compressors were then shut off to allow the water level in the bore hole to recover for about two hours. From the production rate and the rate of recovery, the Jacobs method was used to approximate transmissivity and specific capacity. The values derived are termed "apparent" because: the pumping time was short; the production rate was not constant; drilling was simultaneously occurring with the production; and aquifer intervals of varying pressures were open to the bore hole.

The apparent transmissivities for the upper aquifer ranged from less than 1,000 gallons per day per foot (gpd/ft) to 20,000 gpd/ft. and averaged 5,140 gpd/ft. The apparent transmissivities for the combined aquifers ranged from

less than 200 gpd/ft. to approximately 12,000 gpd/ft. and averaged 3,089 gpd/ft.

The specific capacity is an expression of the production capability in respect to the amount of drawdown experienced at a known production rate and at a given time. A small specific capacity represents limited aquifer inflow into the well. Apparent specific capacities averaged 1.3 gallons per minute per foot (gpm/ft.) for the upper aquifer and 1.5 gpm/ft. for the combined aquifer 2-hour tests.

e. Geophysical Logs - A suite of bore hole geophysical logs were run after the total depth of each hole was reached. For hydrological purposes, the spinner (a flow-meter propeller device which is turned by the force of the flowing water), and temperature surveys are of prime interest. While the spinner surveys are highly interpretive, the temperature surveys are straightforward.

The temperature survey indicates the water temperature in the bore holes versus depth. This data can be used in some cases to interpret the flow, being either downhole or uphole, zones where water is entering or leaving the borehole, or no flow at all.

The spinner survey, though interpretive, is more definitive of direction and velocity of flow versus hole depth. Measurements are made from several runs. The flow rate at any given depth can be calculated from these measurements, knowing the spinner tool specifications and the bore hole size. The rate of water, per foot of depth, entering or leaving the borehole can also be calculated.

f. Completion Program - A dual monitor hole completion was designed to isolate the aquifers in order to obtain water levels and water samples from one hole for the two different aquifers. This method of completion also allows the tubing to be removed so individual zones could be tested or pumped. The completion method for monitor holes was approved by the AOSS. A typical dual completion hole is shown in Figure 3-4-9.

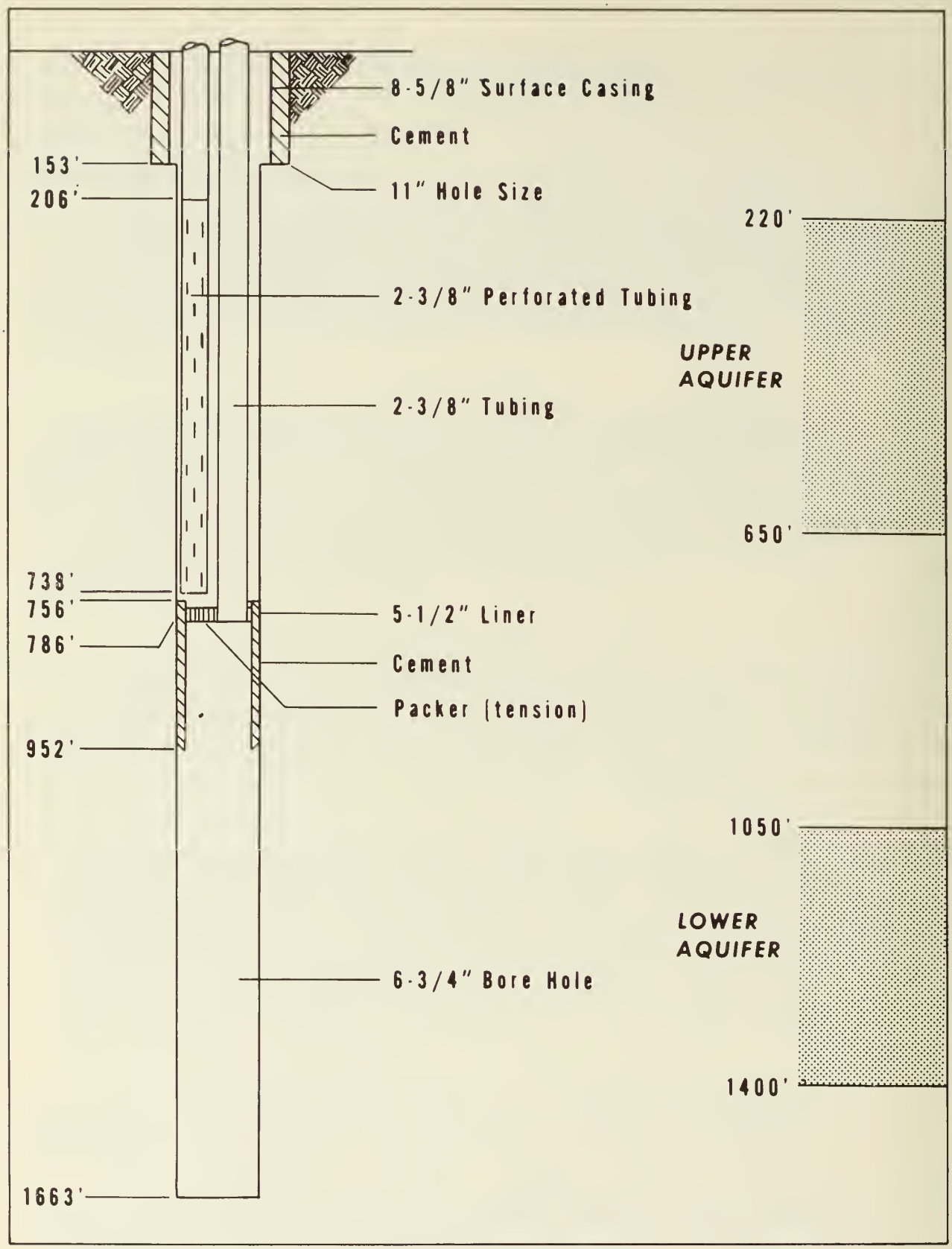


Figure 3-4-9

TYPICAL (SECTION) DUAL MONITOR HOLE COMPLETION

In most cases, a 5-1/2 inch liner, or 4-1/2 inch liner (depending on original hole size) was run in the hole to a depth of approximately 250 feet below the bottom of the upper aquifer, as indicated by preliminary drilling data. Approximately 200 feet of the lower part of this liner was cemented in place. After the cement had set, a cement bond log was run to determine the top of the cement so that the liner could be cut off above the cement. The upper portion of the liner was then removed from the hole. A 2-3/8 inch string of tubing was used to set a tension-type packer in the liner approximately 30 feet below the top of the liner. This string of tubing with the packer and liner act as a seal to isolate the two aquifers and yet allow the lower aquifer to be monitored and sampled.

Two safety joints were designed into the system. These safety joints would allow the packer and possibly up to 60 feet of the tubing to remain in the hole should a situation arise where the packer cannot be pulled. A washover tool could then be used to retrieve the packer and remaining tubing, or allow the packer and a short amount of tubing to be pushed to the bottom of the hole. The first safety joint is located at the packer and the second is 60 feet above the packer.

A second string of tubing was run to insure that data could be collected for the upper aquifer. In most cases, the second string of tubing is 2-3/8 inches in diameter. In some of the older holes, small surface casing was run which only allows the second string to have a diameter of 1-1/2 inches. In both cases, perforated tubing was run where the drilling data indicated the upper aquifer to be present.

Some of the holes were not needed as monitor holes and were cemented from top to bottom as required by the AOSS. Conversion of the RBOSP holes and those holes drilled by previous operators, which include Cameron Engineers, AMOCO, and TOSCO, commenced in early October, 1974. The hole conversions were completed by mid-January, 1975. Table 3-4-11 shows the current status of each of the deep holes on Tract C-a and the five monitor holes located off tract.

Table 3-4-11

DRILL HOLE COMPLETION SUMMARY
TRACT C-a AND VICINITY
Thirty On-Tract Holes

Drill Hole	Completion	Drill Hole	Completion
G-S 1	U&L	Am 4	P&A
G-S 2-3	U&L	CE - 701	Upper Aquifer Pumping Test
G-S 4-5*	U&L*	CE - 702	U&L
G-S 6	U&L	CE - 703	P&A
G-S 7	P&A	CE - 705-A	Upper Aquifer Pumping Test
G-S 8	Lower Aquifer Only	CE - 707	U&L
G-S 9	U&L	CE - 708	U&L
G-S 10	U&L	CE - 709	U&L
G-S 11	U&L	TO 1	U&L
G-S 12*	U&L*	TO 2	U&L
G-S 13	U&L	TO 3	Upper Aquifer Pumping Test
G-S 14	P&A	G-S D16	Lower Aquifer Pumping Test
G-S 15	U&L	G-S D17	Lower Aquifer Pumping Test
Am 2-A	U&L	G-S D18	Lower Aquifer Pumping Test
Am 3	U&L	G-S D19	Lower aquifer Pumping Test

Four Off-Tract Holes

Drill Hole	Completion
G-S M1	U&L
G-S M2	U&L
G-S M3	U&L
G-S M4	U&L
G-S M5	AU

Totals

Completions in Upper and Lower Aquifers	22
Completions in Upper Aquifer Only	3
Completions in Lower Aquifer Only	5
Completions in Uinta Fm. Aquifers	1
Holes Plugged and abandoned	4
Total Number of Holes	35

Am = Amoco Production Company
CE = Cameron Engineers, Inc.
G-S = Gulf-Standard (Indiana)
TO = The Oil Shale Corporation
U&L = Upper and Lower Aquifer Completions
P&A = Plugged and Abandoned
AU = Aquifers, Uinta Fm.

*Holes Temporarily Modified for Upper Aquifer Pumping Test

g. Upper and Lower Aquifer Pumping Tests - As part of the Exploratory Plan, as amended and approved by the AOSS, four upper aquifer pump tests and four lower aquifer pump tests were conducted. These pump tests were conducted to determine aquifer characteristics such as transmissivity, coefficient of storage, leaky conditions, boundary and recharge barriers. The tests began in January, 1975, and were concluded in June, 1975.

The aquifer tests included the monitoring of drawdown and recovery in both the production hole and all observation holes. Figure 3-4-5 shows the various hole locations. The water levels in the production holes were measured with an air line except for the second and third tests of CE 705-A and G-S 4-5 for which an electric water-level indicator was used. All observation holes were monitored with an electric water-level indicator. Constant production rates in gallons per minute were measured on a regular basis. Submersible pumps were used. Pump installation diagrams are shown on Figures 3-4-10 through 3-4-12. These figures show the location of pump placement downhole with respect to the associated hole completion technique and aquifer location. Upper aquifer tests were conducted by pumping TO 3, CE 705-A, G-S 12 and G-S 4-5. Lower aquifer pump tests were conducted at G-S D17, G-S D16, G-S D19, and simultaneously at G-S D18 and G-S D19. The pumping tests, including pumping rates and total time pumped, are shown in Table 3-4-12.

During the pumping tests, the temperature, conductivity, and pH were monitored as specified by the AOSS. The water quality of the upper aquifer was stable over the pumping period except at the initiation of pumping. This initial change in conductivity and pH is due to the removal of fluids introduced during drilling. For the upper aquifer, the average pH value ranged from 6.8 to about 7.5 for the wells tested.

Temperature fluctuated during the first stages of pumping and tended to stabilize after a few days of pumping. Upper aquifer pumping tests in holes G-S 12 and CE 705-A produced the lowest temperature water, averaging about 14°C. G-S 4-5 produced water at a relatively constant value of 17°C. TO 3, in contrast, showed fluctuating temperature values that averaged 23°C.

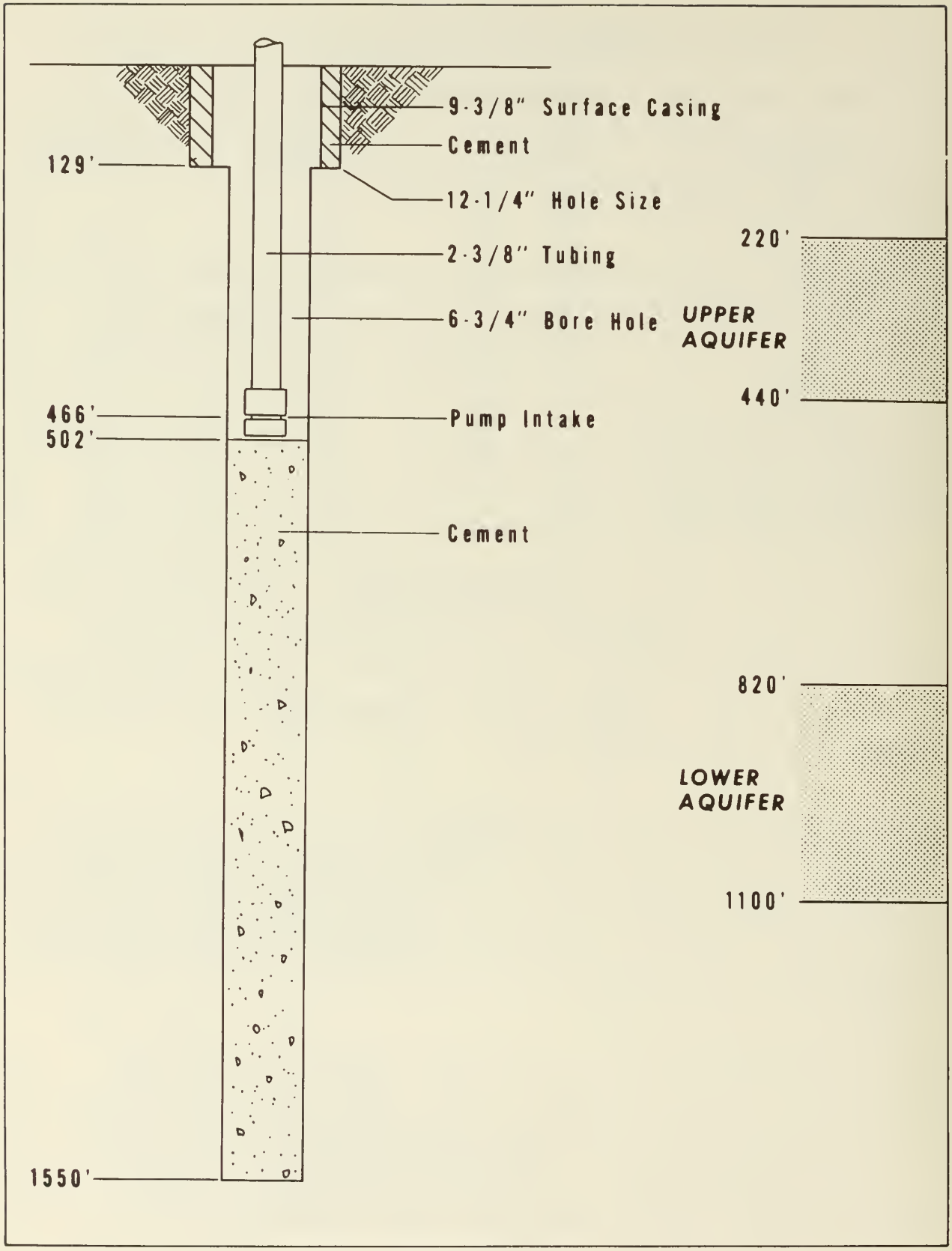


Figure 3-4-10

TYPICAL SECTION UPPER AQUIFER PUMPING TEST HOLE

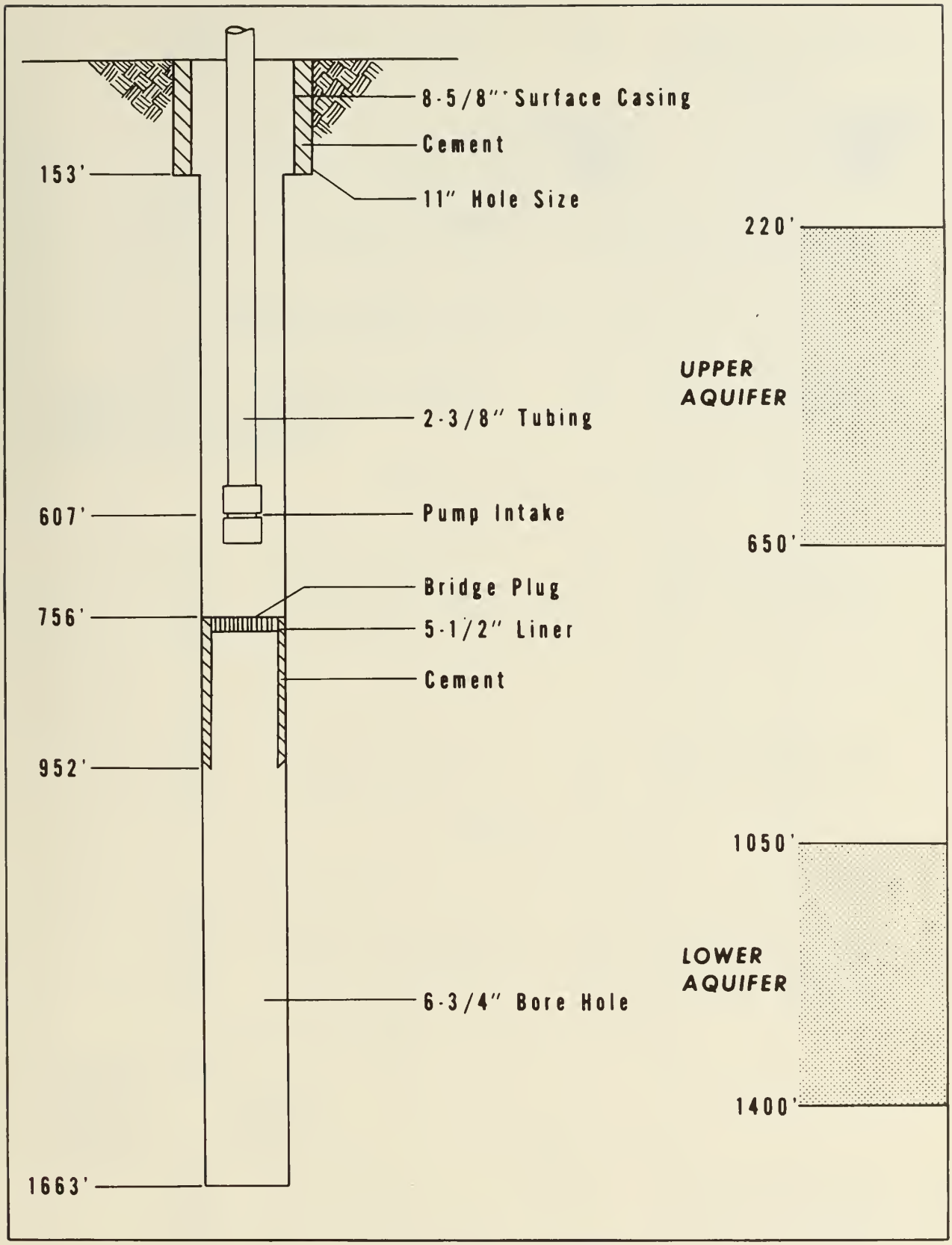


Figure 3-4-11

TYPICAL SECTION DUAL AQUIFER MONITOR HOLE
USED AS UPPER AQUIFER PUMPING TEST HOLE

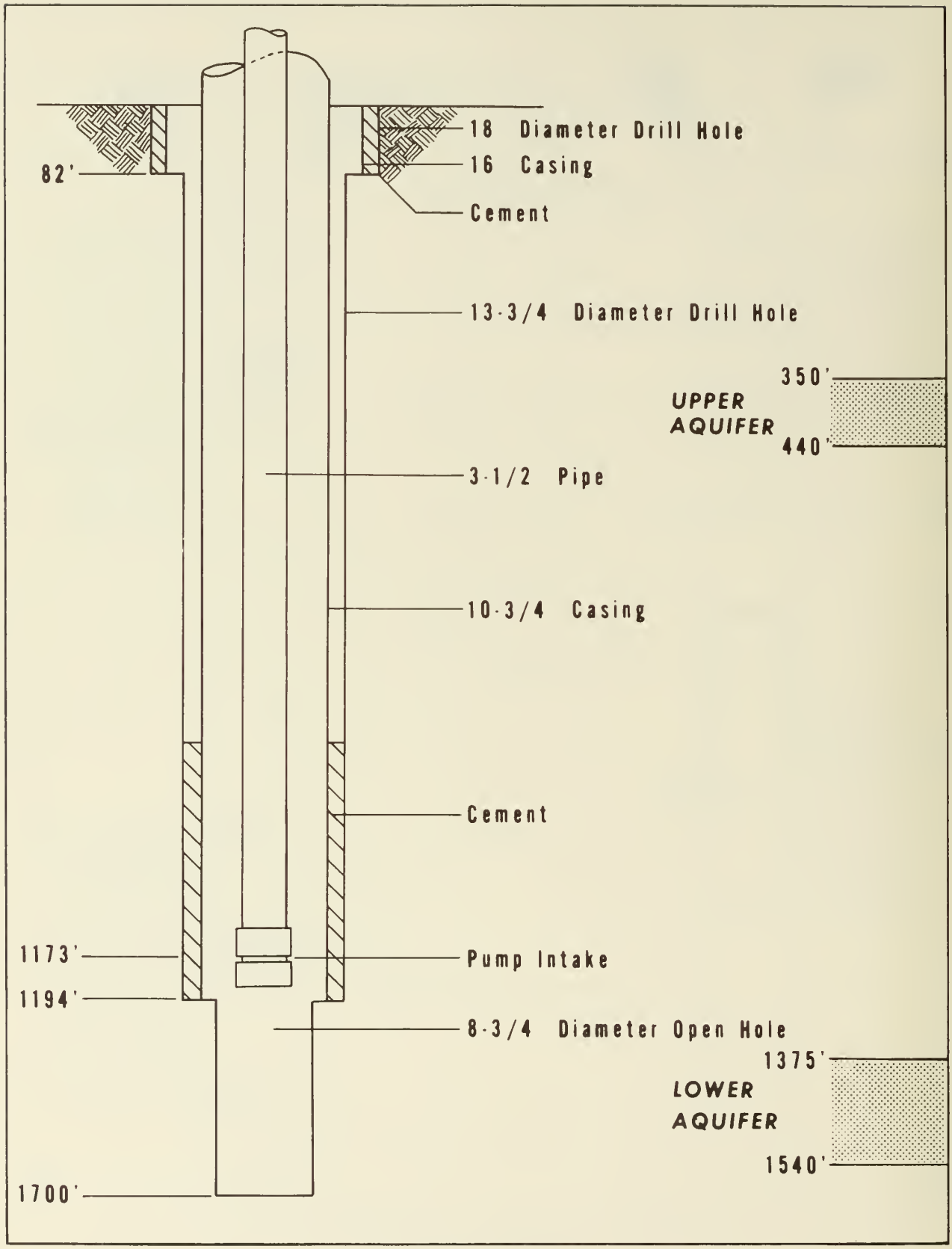


Figure 3-4-12

TYPICAL SECTION LOWER AQUIFER
PUMPING TEST HOLE

Table 3-4-12

PUMPING RATES & TIMES

Pumped Hole	Date Pump Turned On	Time Pump Turned On	Date Pump Turned Off	Time Pump Turned Off	Gallons Pumped per Minute	Total Time of Pumping (min.)
Upper Aquifer						
CE 705-A	2/26/75	1230	3/08/75	0850	72	14180
CE 705-A	3/19/75	0905	3/22/75	1405	264	4620
CE 705-A	3/25/75	0825	4/01/75	1515	259	10490
G-S 4-5	5/02/75	0945	5/19/75	0715	81.3	24330
G-S 12	4/02/75	1045	4/13/75	0845	64.3	15720
TO 3	1/07/75	1000	1/28/75	1310	76.7	30430
Lower Aquifer						
G-S 16	2/11/75 (Step Drawdown)	0945	2/11/75	1800	151 200 250	495
G-S D16	2/15/75	1300	3/09/75	1230	123	31650
G-S D17	1/06/75	1600	1/11/75	0928	275	6808
G-S D17	1/18/75	1300	2/03/75	0830	275	22770
G-S D18	5/21/75	1030	6/05/75	1100	174	21630
G-S D19	4/08/75	1100	5/05/75	0030	667	38250
G-S D19	5/20/75	1000	5/26/75	0655	667	8455

Conductivity fluctuated or dropped at the start of most pumping tests but stabilized shortly thereafter. In the upper aquifer, conductivity from G-S 12, CE 705-A and G-S 4-5 ranged from about 1,350 umhos/cm to 1,750 umhos/cm. TO 3, however, averaged higher, 3,500 umhos/cm. This is possibly due to interconnection with higher conductivity water from the lower aquifer.

Quality of water from the lower aquifer was poorer than upper aquifer water. Water from G-S D16, G-S D19, and G-S D18 had relatively stable pH, averaging 7.5. G-S D17 fluctuated between a pH of 6.0 and 7.3 Temperature from G-S D19 water increased gradually from 17°C to 19°C. Temperatures in the other wells fluctuated: G-S D16 ranged from 24°C to 27°C and stabilized at 27°C about mid-test; G-S D17 ranged from about 13°C to 18°C; and G-S D18 ranged from 28°C to 30°C, and stabilized at 30°C at mid-test.

Conductivity from G-S D17 water was generally stable at 1,700 umhos/cm. G-S D18 conductivity stabilized just less than 5,000 umhos/cm. Higher conductivities are probably due to the solution of leachable salts as the water moved through the aquifer. G-S D19 water conductivity gradually increased from 1,800 umhos/cm. to 2,400 umhos/cm. G-S D16 conductivity gradually dropped from about 4,200 to 3,800 umhos/cm.

Values of transmissivity (T) and coefficients of storage (S) for the pumped hole and all affected observation holes were computer-calculated and plotted using the simplified Jacob's method. Figure 3-4-13 is a typical Jacob's plot. The T's and S's summarized in Table 3-4-13 are an arithmetic mean of the representative T's and S's from the pumping tests. The average T's and S's given in the text for the upper and lower aquifers are an arithmetic mean.

The effects of the upper aquifer pumping tests were observed primarily only in nearby holes. The average T and S during drawdowns were 15,316 gpd/foot and 6.8×10^{-5} respectively. The average T and S during recovery were 16,909 gpd/foot and 5.97×10^{-5} respectively.

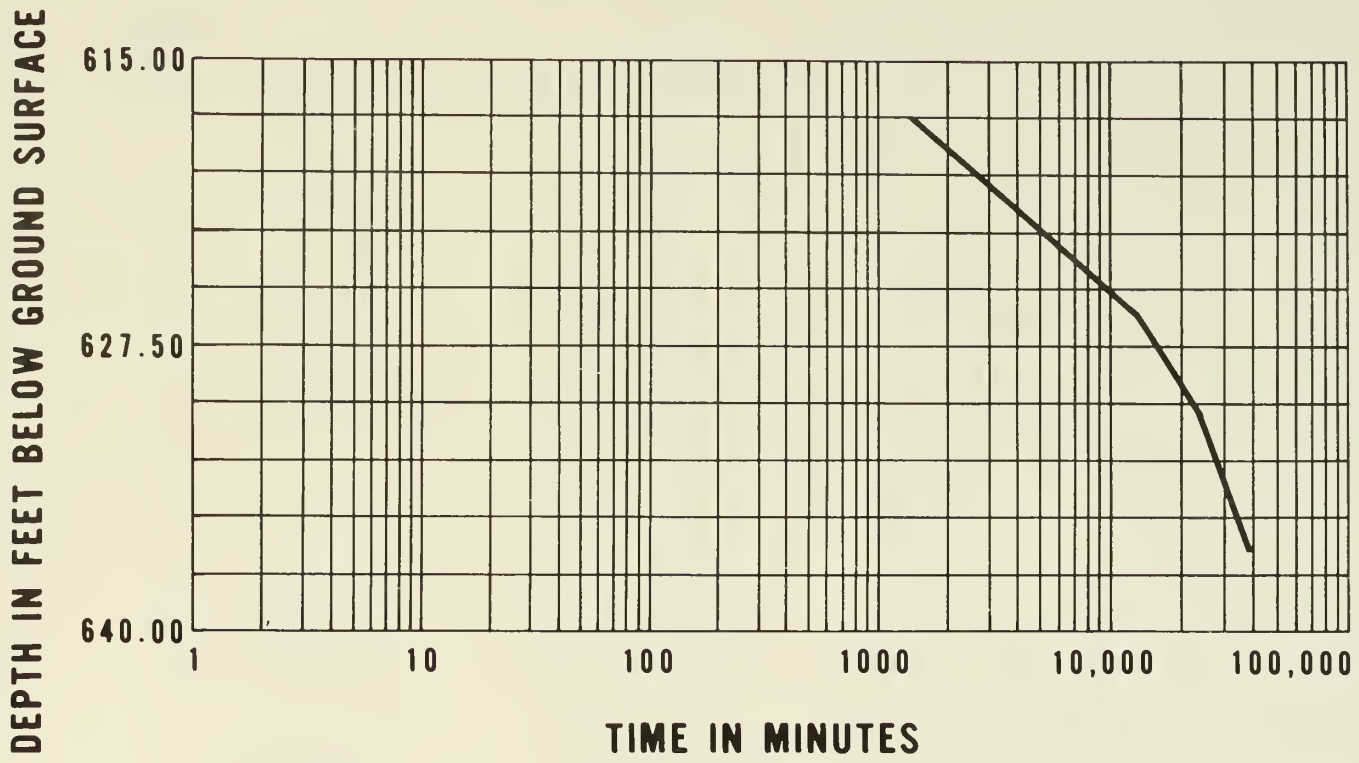


Figure 3-4-13
TYPICAL JACOB'S PLOT

Table 3-4-13

PUMPING TEST SUMMARY

Pumping Hole	Average from Drawdown T	Average from Drawdown S	Average from Recovery T	Average from Recovery S
Upper Aquifer				
CE 705-A	--	--	25925 (2)	1.86E-5 (1)
CE 705-A	17767 (3)	2.26E-5 (2)	16990 (3)	3.31E-5 (2)
CE 705-A	29348 (4)	4.51E-5 (3)	24891 (4)	4.22E-5 (2)
G-S 4-5			5176 (1)	--
G-S 12	2381 (4)	1.06E-4 (3)	7569 (2)	2.72E-6 (1)
TO 3	11769 (3)	9.9E-5 (3)	20905 (2)	2.02E-4 (2)
Lower Aquifer				
G-S D16	--	--	--	--
G-S D16	6458 (22)	1.19E-4 (22)	58109 (11)	1.91E-5 (11)
G-S D17	12218 (7)	1.09E-4 (7)	19025 (10)	1.41E-4 (8)
G-S D17	7547 (21)	6.21E-5 (20)	24602 (18)	6.76E-5 (18)
G-S D18	--	--	22843 (21)	5.38E-5 (20)
G-S D19	7041 (22)	1.78E-4 (21)	22890 (22)	1.25E-4 (22)
G-S D19	14598 (19)	8.04E-5 (18)	43461 (21)	1.65E-4 (20)

( ) number of observation holes used in calculation
E-5 = 10^{-5} etc.

Each of the lower aquifer pumping tests generally affected all of the lower aquifer observation holes with the exceptions of G-S M2 and G-S M3. The lack of effect in these holes is probably due to the partial penetration of the lower aquifer by these holes resulting in a poor hydrologic connection with the aquifer. The lower aquifer average transmissivities are less than the upper aquifer values, with an average T of 9,572 gpd/foot, and an S of 2.0×10^{-4}. The generally higher values of transmissivity during recovery than during drawdown are probably due to the lowering of piezometric level of the lower aquifer during pumping, resulting in the aquifer never fully recovering from the pumping.

There appears to be a connection between the upper and lower aquifers in the northeast corner of the tract in the area of CE 702, G-S 6, and TO 3, indicated by the drawdown and recovery of the upper aquifer during the pumping tests of G-S D19 and G-S D18 simultaneously.

A step drawdown test of the lower aquifer was conducted in G-S D16. The results indicate an average transmissivity of 15,538 gpd/foot. The average drawdown, T and S for the long-term drawdown test of G-S D16 were 6,458 gpd/foot and 1.19×10^{-4} respectively. Some of the observation holes had insufficient recovery to calculate a T or S.

Geophysical well logs were run in G-S 12 and TO 1 during pumping tests to determine the lower aquifer nature on a foot-by-foot basis. These logs included: temperature, acoustic flow, and radio-active tracer surveys. During the pumping of G-S D16 a radio-active tracer was run in G-S 12. The interpretation of this log is inconclusive as to where water may be flowing through the bore hole. During the pumping of G-S D19, all three of the above mentioned logs were run.

h. Monitoring - The deep aquifer monitoring program was initiated in December 1974. Early data consisted of measuring water levels. These were both static water levels and dynamic water levels as the result of the pumping program, as shown in Figures 3-4-14 and 3-4-15. The sampling program began in March, 1975. For a period of 6 months, water samples were collected monthly and analyzed for the constituents as outlined by the AOSS.

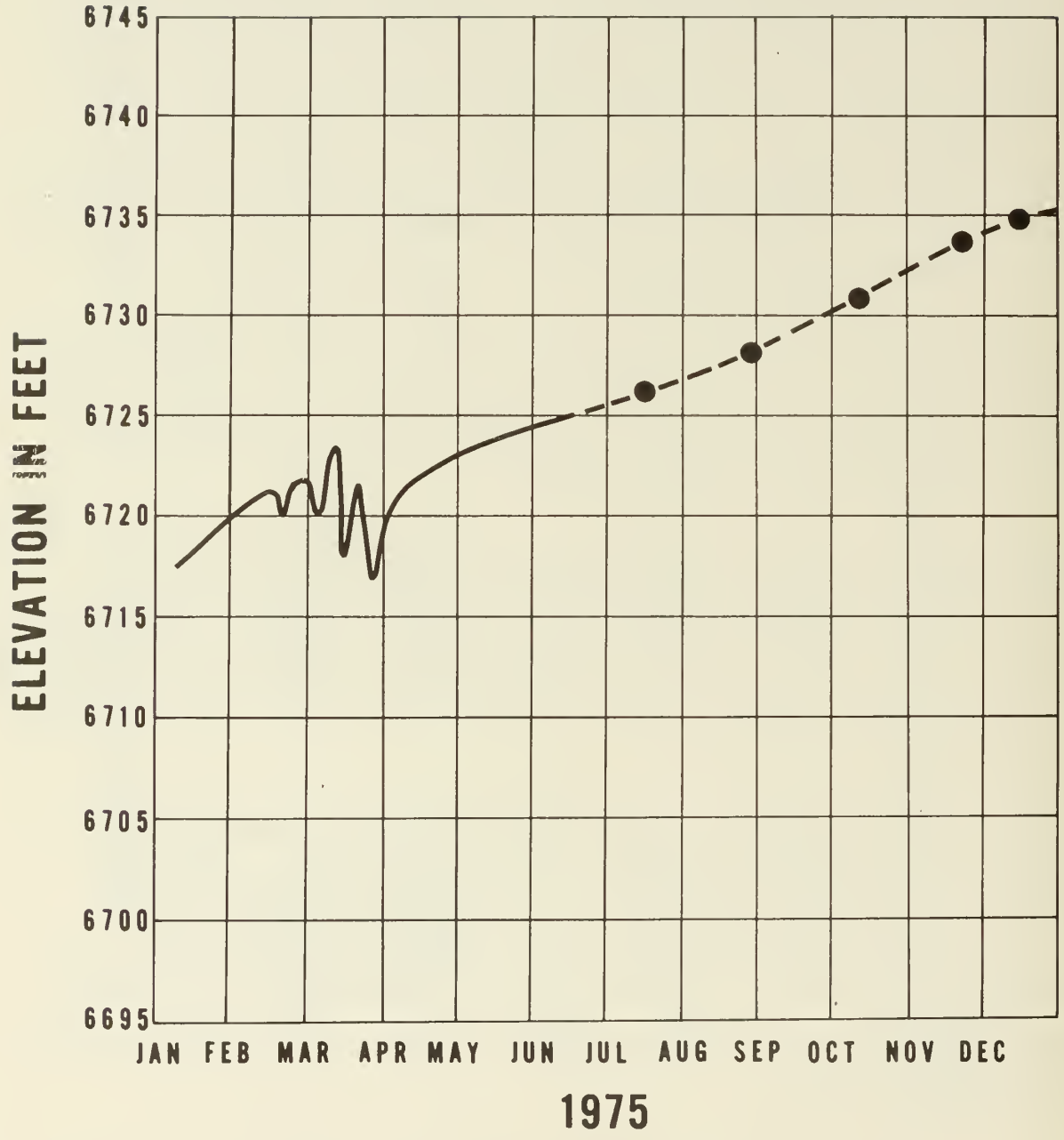


Figure 3-4-14

TYPICAL UPPER AQUIFER HYDROGRAPH
(From CE 709)

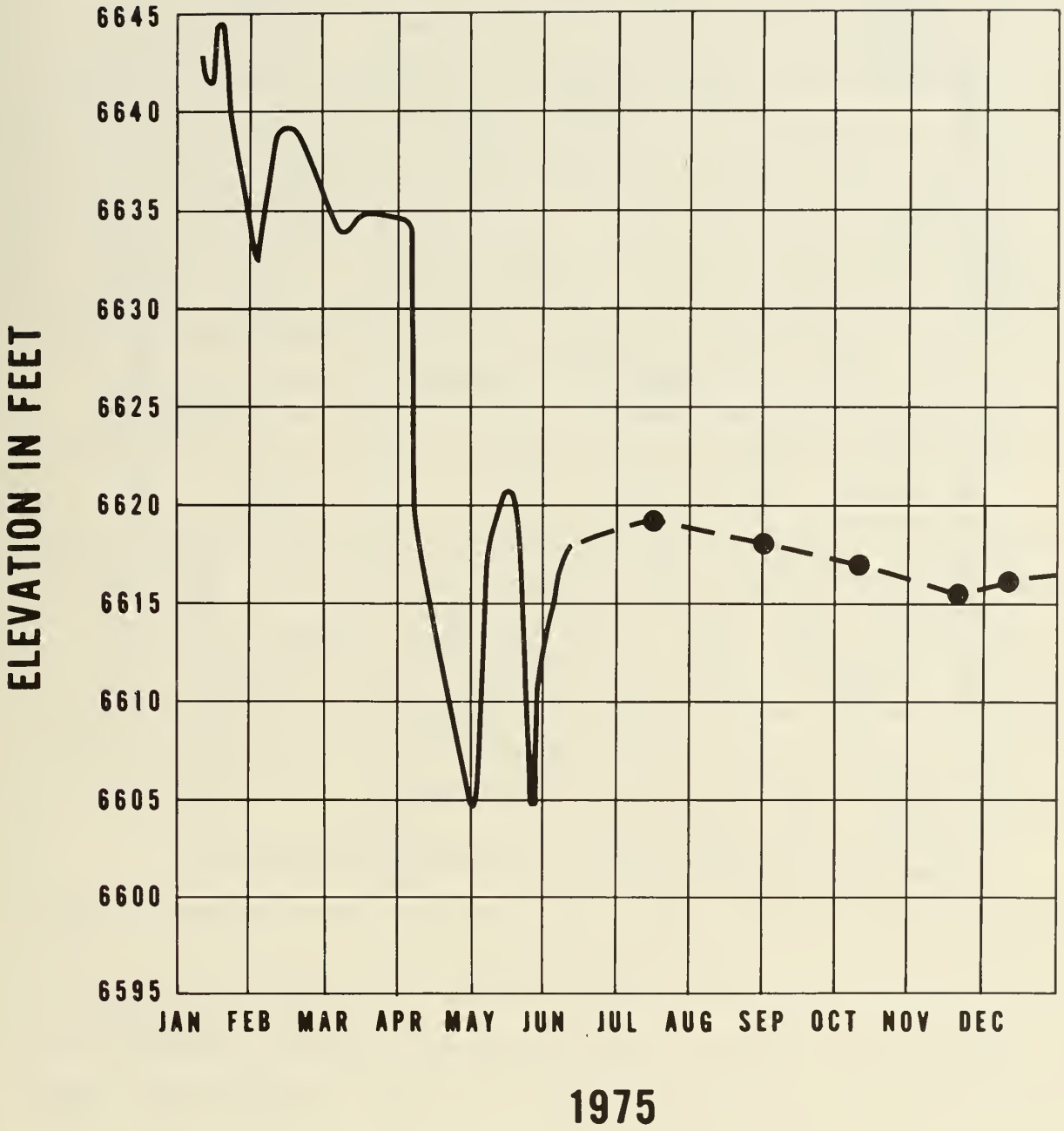


Figure 3-4-15

TYPICAL LOWER AQUIFER HYDROGRAPH
(From CE 709)

As per the Gulf-Standard Exploratory Plan, the sampling program after the first 6 months consists of monitoring static water levels and water temperatures on a monthly basis and water samples are to be collected once every 6 months for analysis of the chemical constituents required by the AOSS.

Figures 3-4-16 and 3-4-17 show the upper and lower aquifer piezometric levels respectively. A comparison of these two piezometric level maps indicates that the upper aquifer has a higher level when compared to the lower aquifer except in the northeast corner of the tract. It should also be noted that, in general, both aquifers have a downward slope to the northeast; however, the upper aquifer has a much steeper gradient, approximately 150 feet per mile when compared to the lower aquifer, which has a gradient of approximately 10 feet per mile. The piezometric levels intersect in the northeast corner of the tract and diverge toward the center of the basin. Thus, northeast of the tract the lower aquifer has a higher piezometric level than the upper aquifer.

The water levels in each of the holes have been changing with time. In general, the upper aquifer holes have shown an increase in head and the lower aquifer holes a decrease in head. This is due to the aquifers recovering from the 1971-1974 prelease conditions in which prelease exploration holes drilled through both aquifers had been left open. The result was that water flowed from the upper aquifer into the lower aquifer, thereby creating a depression in the upper aquifer piezometric levels and a mound in the lower aquifer piezometric levels in and around Tract C-a.

During the period of January, 1975, through December, 1975, the depth to water in AM 2A, AM 3, CE 707, CE 708, CE 709, G-S 2-3, G-S 9, G-S 11, G-S 12, G-S M1 and TO 2 has decreased up to 2 feet per month. The heads in the remaining upper aquifer monitor holes have remained relatively constant from July, 1975, through December, 1975, the depth to water in the lower aquifer monitor holes has increased about 1-1/2 feet per month.

The results of the water quality monitoring program are summarized in Table 3-4-14 which indicates a low, high and average value for each of the chemical constituents. Table 3-4-15 is a summary of the spectrographic analysis and

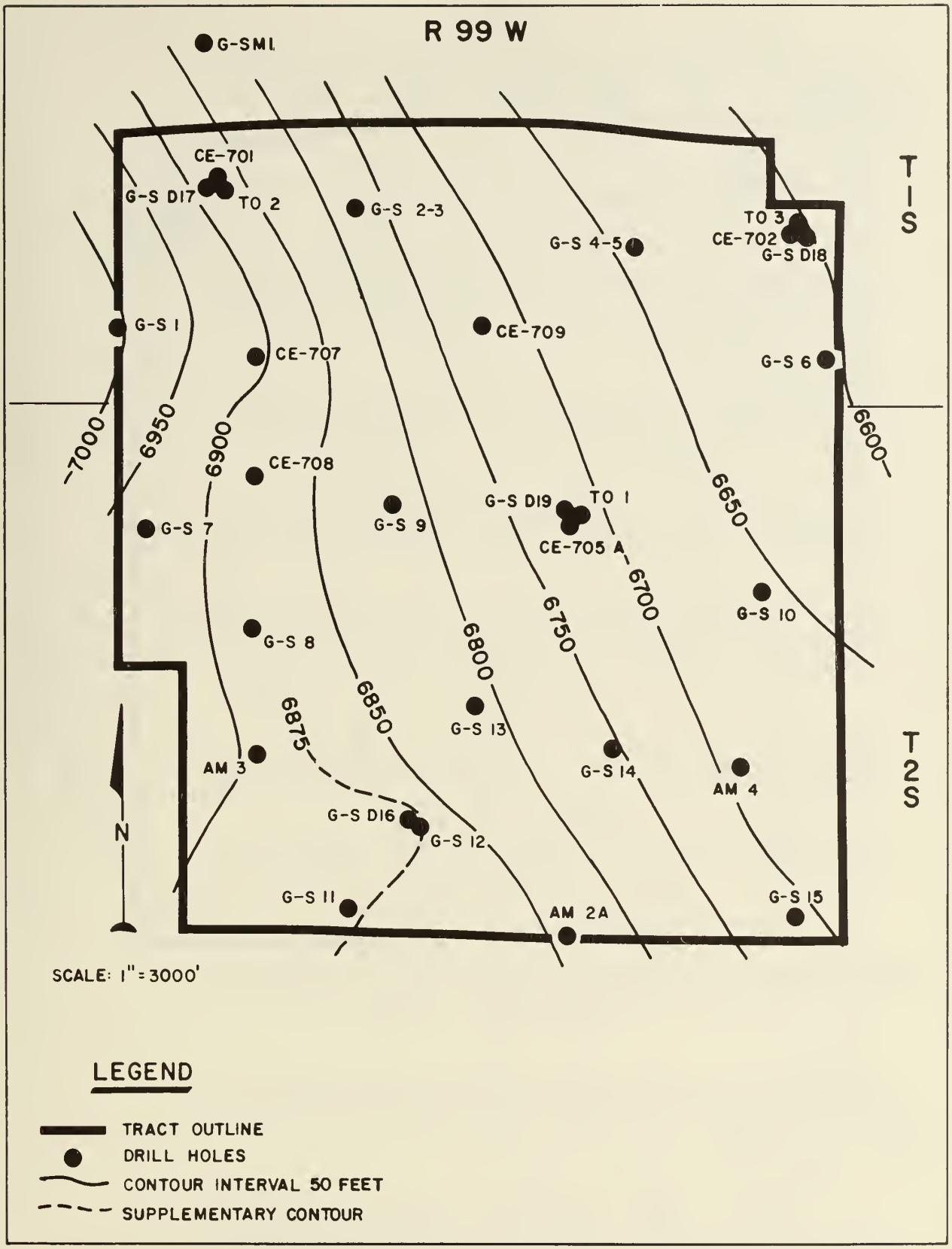


Figure 3-4-16

UPPER AQUIFER PIEZOMETRIC LEVELS (ft)
August 30, 1975

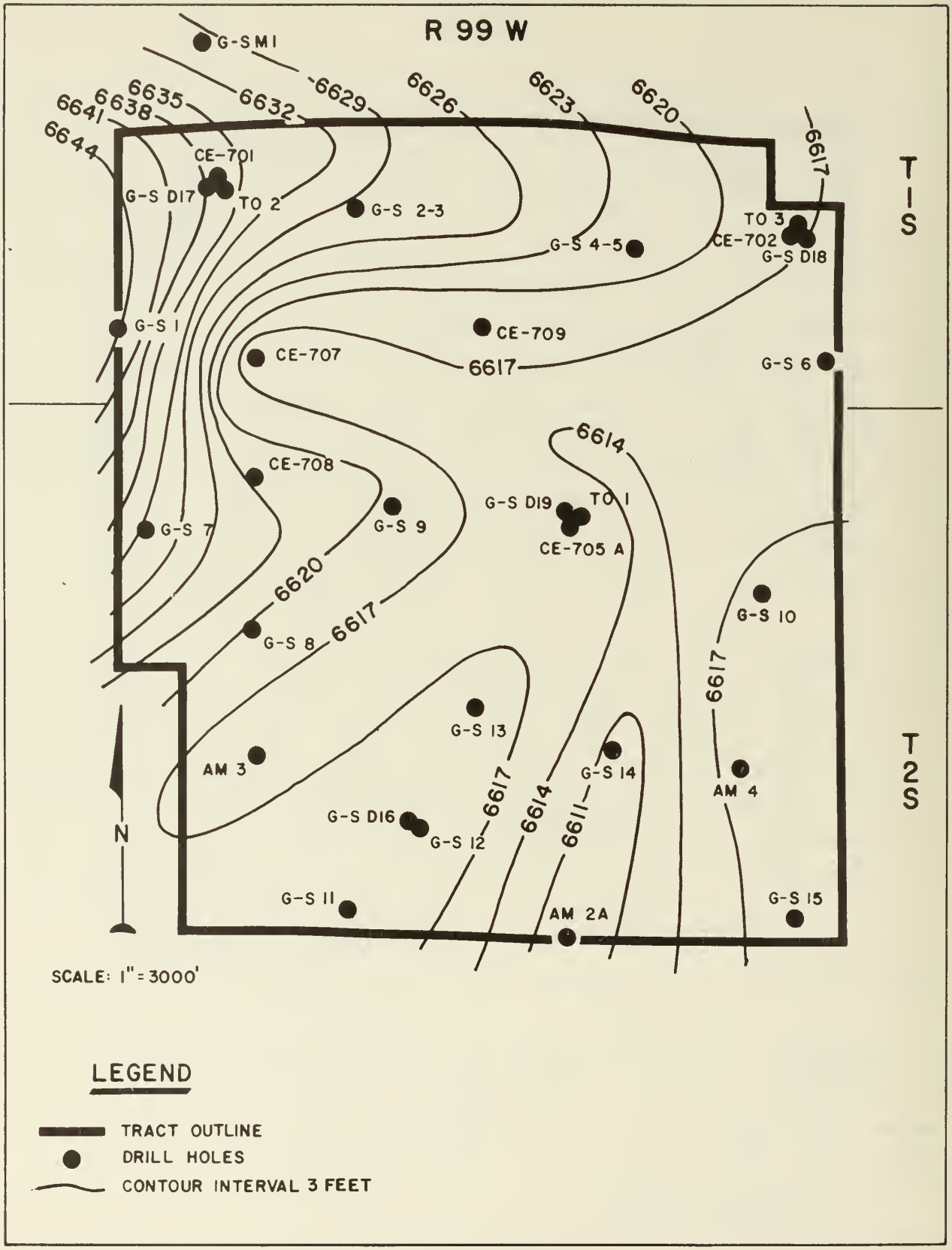


Figure 3-4-17

LOWER AQUIFER PIEZOMETRIC LEVELS (ft)
August 30, 1975

Table 3-4-14

OIL SHALE AQUIFERS WATER ANALYSIS SUMMARY
WET CHEMICAL
(all values in mg/l)
July, 1974 Through January, 1976

	LOWER AQUIFER					UPPER AQUIFER				
ITEM	LOW	HIGH	AVERAGE	# ITEMS AVERAGED	STD DEV.	LOW	HIGH	AVERAGE	# ITEMS AVERAGED	STD DEV.
ALUMINUM	-0.100	1.600	0.120	45	0.278	-0.100	2.200	0.176	46	0.387
ALKALINITY	-0.100	10500.000	910.000	180	1110.000	-0.100	2360.000	515.000	163	467.000
AMMONIA	-0.100	9.600	0.628	150	0.992	-0.100	10.600	0.624	166	1.110
ARSENIC	-0.050	0.050	0.001	170	0.005	-0.050	0.200	0.004	177	0.018
BARIUM	-1.000	-0.100	0.000	166	0.000	-1.000	-0.100	0.000	137	0.000
BICARBONATE	-0.100	11800.000	1070.000	185	1250.000	-0.100	2760.000	608.000	205	490.000
BORON	-0.100	25.000	1.830	168	3.360	-0.100	4.800	0.692	148	1.020
CADMIUM	-0.010	0.030	0.001	171	0.004	-0.010	0.100	0.002	161	0.009
CALCIUM	-1.000	515.000	38.300	185	73.200	-0.010	780.000	66.000	205	70.900
CARBONATE	-1.000	3160.000	95.400	185	262.000	-0.100	1190.000	33.600	204	96.800
CHLORIDE	-1.000	205.000	34.100	185	38.700	-1.000	240.000	24.600	205	32.600
CHROMIUM	-0.050	0.010	0.000	166	0.001	-0.050	0.500	0.005	162	0.043
CONDUCTANCE	760.000	15800.000	2260.000	183	1940.000	675.000	6200.000	1530.000	204	780.000
COPPER	-0.100	0.300	0.018	171	0.049	-0.100	0.800	0.027	161	0.102
CYANIDE	-0.100	0.800	0.005	165	0.062	-0.010	-0.010	0.000	136	0.000
DIS. SOLIDS	430.000	12200.000	1550.000	184	1280.000	425.000	3140.000	1140.000	205	511.000
FLUORIDE	-0.050	120.000	13.700	186	20.600	0.060	80.000	4.090	205	10.500
GROSS ALPHA	0.100	86.000	6.408	133	9.900	0.200	29.000	5.080	117	4.880
GROSS BETA	3.000	830.000	53.100	50	123.000	2.000	73.000	21.600	31	17.900
HARDNESS	20.000	1260.000	245.000	185	214.000	16.000	1870.000	379.000	205	238.000
HYDROXIDE	-0.100	890.000	221.000	8	410.000	-0.100	380.000	9.270	41	59.300
IRON	-0.050	33.000	3.160	185	4.550	-0.050	18.000	4.150	189	4.730
LEAD	-0.100	26.000	0.647	171	2.540	-0.050	3.800	0.353	161	0.554
MAGNESIUM	-1.000	140.000	37.000	185	31.200	-0.100	155.000	51.900	204	32.100
MANGANESE	-0.050	0.500	0.066	179	0.095	-0.100	1.000	0.125	177	0.158
MERCURY	-0.010	0.002	0.000	167	0.000	-0.010	0.045	0.000	164	0.004
NICKEL	-0.100	0.100	0.023	164	0.019	-0.010	0.200	0.027	137	0.028
NITRATE	-0.100	55.000	0.765	185	4.180	-0.100	7.000	0.534	205	0.883
PH	6.000	12.200	7.350	185	0.835	6.000	10.200	7.040	205	0.677
PHOSPHATE	-0.100	2.400	0.046	172	0.207	-0.100	9.200	0.184	164	0.949
POTASSIUM	-1.000	84.000	26.800	5	34.800	-1.000	93.000	12.773	41	24.300
SELENIUM	-0.100	-0.001	0.000	171	0.000	-0.100	0.010	0.000	178	0.001
SIL. DIOXIDE	-0.100	50.000	11.355	185	9.367	-0.100	58.000	26.000	205	14.700
SILVER	-0.010	0.110	0.003	166	0.015	-0.100	0.100	0.007	137	0.019
SODIUM	86.000	5290.000	524.000	185	563.000	40.000	1170.000	273.000	205	212.000
SULFATE	-10.000	740.000	219.000	185	174.000	-4.000	900.000	334.000	205	169.000
SULFIDE	-0.010	2.400	1.470	3	1.290	-1.000	26.000	2.840	19	5.760
ZINC	-0.500	68.000	1.340	171	6.400	-.500	15.000	0.681	152	1.540

Table 3-4-15

OIL SHALE AQUIFERS WATER ANALYSIS SUMMARY
QUALITATIVE SPECTROGRAPHIC
(all values in mg/l)
July, 1974, Through January, 1976

	LOWER AQUIFER					UPPER AQUIFER				
ITEM	LOW	HIGH	AVERAGE	# ITEMS AVERAGED	STD. DEV.	LOW	HIGH	AVERAGE	# ITEMS AVERAGED	STD DEV.
ALUMINUM	0.001	5.000	0.138	174	0.412	0.001	1.000	0.155	197	0.210
ANTIMONY	0.200	0.200	0.200	1	0.000	---	---	---	0	0.000
ARSENIC	---	---	---	0	0.000	---	---	---	0	0.000
BARIUM	0.001	0.100	0.017	27	0.033	0.001	0.050	0.005	25	0.010
BERYLIUM	---	---	---	0	0.000	---	---	---	0	0.000
BISMUTH	---	---	---	0	0.000	---	---	---	0	0.000
BORON	0.050	MAJOR	0.443	173	0.658	0.020	5.000	0.353	197	0.431
CADMIUM	MAJOR	MAJOR	0.000	0	0.000	MAJOR	MAJOR		0	0.000
CALCIUM	0.100	MAJOR	6.650	34	4.400	1.000	MAJOR	7.160	19	3.980
CERIUM	---	---	---	0		---	---	---	0	0.000
CESIUM	---	---	---	0	0.000	---	---	---	0	0.000
CHROMIUM	0.001	0.010	0.005	2	0.006	---	0.050	0.010	13	0.013
COBOLT	---	---	---	0	0.000	0.001	0.001	0.001	1	0.000
COLUMBIUM	---	---	---	0	0.000	---	---	---	0	0.000
COPPER	0.001	0.100	0.007	150	0.010	---	0.050	0.008	158	0.010
DYSPROSIUM	---	---	---	0	0.000	---	---	---	0	0.000
ERBIUM	---	---	---	0	0.000	---	---	---	0	0.000
EUROPIUM	---	---	---	0	0.000	---	---	---	0	0.000
GADOLINIUM	---	---	---	0	0.000	---	---	---	0	0.000
GALLIUM	---	---	---	0	0.000	---	---	---	0	0.000
GERMANIUM	---	---	---	0	0.000	---	---	---	0	0.000
GOLD	---	---	---	0	0.000	---	---	---	0	0.000
HAFNIUM	---	---	---	0	0.000	---	---	---	0	0.000
HOLMIUM	---	---	---	0	0.000	---	---	---	0	0.000
INDIUM	---	---	---	0	0.000	---	---	---	0	0.000
IRIDIUM	---	---	---	0	0.000	---	---	---	0	0.000
IRON	0.005	5.000	0.119	174	0.540	0.010	1.000	0.097	194	0.166
LANTHANUM	---	---	---	0	0.000	---	---	---	0	0.000
LEAD	---	0.500	0.048	19	0.119	0.001	0.500	0.048	32	0.099
LITHIUM	0.001	5.000	0.053	132	0.435	---	0.500	0.027	136	0.059
LUTETIUM	0.010	0.010	0.010	1	0.000	0.001	0.010	0.005	2	0.006
MAGNESIUM	0.100	MAJOR	3.610	34	2.800	0.100	MAJOR	6.200	22	4.050
MANGANESE	0.001	0.200	0.017	135	0.032	0.001	1.000	0.030	141	0.090
MERCURY	---	---	---	0	0.000	---	---	---	0	0.000
MOLYBDENUM	0.001	0.100	0.006	76	0.015	0.001	0.500	0.016	93	0.073
NEODYMIUM	0.090	0.090	0.090	1	0.000	---	---	---	0	0.000
NICKEL	---	---	---	0	0.000	0.001	0.010	0.007	3	0.005
OSMIUM	---	---	---	0	0.000	---	---	---	0	0.000
PALLADIUM	---	---	---	0	0.000	0.100	0.100	0.100	1	0.000
PLATINUM	---	---	9.000	0	0.000	---	---	0.100	1	0.000
POTASSIUM	0.010	MAJOR	1.355	166	1.525	0.050	MAJOR	1.121	180	1.482
PRASEODYMI	---	---	---	0	0.000	---	---	---	0	0.000
RADIUM	0.090	2.100	0.412	42	0.389	0.100	0.800	0.194	31	0.150
RHENIUM	---	---	---	0	0.000	---	---	---	0	0.000
RHODIUM	---	---	---	0	0.000	---	---	---	0	0.000
RUBIDIUM	---	---	---	0	0.000	---	---	---	0	0.000
RUTHENIUM	---	---	---	0	0.000	---	---	---	0	0.000
SAMARIUM	---	---	---	0	0.000	---	---	---	0	0.000
SCANDIUM	---	---	---	0	0.000	---	---	---	0	0.000
SELENIUM	---	---	---	0	0.000	---	---	---	0	0.000
SILICON	---	MAJOR	5.690	173	4.030	1.000	50.000	9.780	197	8.690
SILVER	0.000	0.001	0.001	13	0.000	0.001	0.001	---	18	0.000
SODIUM	0.100	MAJOR	7.180	82	2.720	2.000	MAJOR	6.940	89	2.910
STRONTIUM	0.001	MAJOR	0.115	156	0.132	0.001	1.000	0.136	162	0.128
TANTALUM	---	---	---	0	0.000	---	---	---	0	0.000
TERBIUM	---	---	---	0	0.000	---	---	---	0	0.000
THALLIUM	---	---	---	0	0.000	---	---	---	0	0.000
THORIUM	1.000	1.000	1.000	1	0.000	---	---	---	0	0.000
THULIUM	---	---	---	0	0.000	---	---	---	0	0.000
TIN	0.001	0.001	0.001	1	0.000	0.001	0.001	0.001	1	0.000
TITANIUM	0.001	0.050	0.004	77	0.007	0.001	0.150	0.011	112	0.023
TUNGSTEN	---	---	---	0	0.000	---	---	---	0	0.000
URANIUM	-1.500	-1.500	---	2	0.000	---	---	---	0	0.000
VANADIUM	---	---	---	0	0.000	0.001	0.100	0.027	16	0.027
YTTERBIUM	---	---	---	0	0.000	---	---	---	0	0.000
YTTRIUM	---	---	---	0	0.000	---	---	---	0	0.000
ZINC	0.001	0.500	0.036	37	0.117	0.001	0.500	0.029	45	0.082
ZIRCONIUM	---	---	---	0	0.000	---	---	---	0	0.000

has dashed lines where the element was either not present or below detectable limits. Where major quantities were encountered, the term "major" is shown.

Figures 3-4-18 and 3-4-19 show the total dissolved solids concentrations in mg/l for the upper and lower aquifers, respectively. The upper aquifer system is found to have better water quality than the lower aquifer system. The average dissolved solids are approximately 1150 mg/l and 1460 mg/l for the upper and lower aquifers, respectively.

Generally, the lower aquifer was found to contain higher concentrations of all the constituents analyzed for, with the exception of the following, which occurred in lower concentrations.

calcium	magnesium	sulphate
chromium	phosphate	hardness
copper	silicon dioxide	manganese

4.4 SUMMARY AND ANALYSIS

A. Precipitation - The precipitation data from the three recording gaging stations indicate a range of 12.1 to 17.4 inches of precipitation per year. The lowest value was recorded at the mouth of Yellow Creek which is the lowest elevation. The highest value was recorded at the Cathedral Bluffs station, which is at the highest elevation of the three stations.

The three storage precipitation gages located near the western tract boundary averaged approximately 9.2 inches of precipitation. It should be noted, however, that during the month of July, 1975, evaporation losses occurred. Because of the heavy July rains, it is believed the average should be adjusted up by 10 percent, giving an approximate adjusted annual precipitation of 10 inches per year. This adjustment would revise Table 3-4-2 to the interpreted results shown in Table 3-4-16.

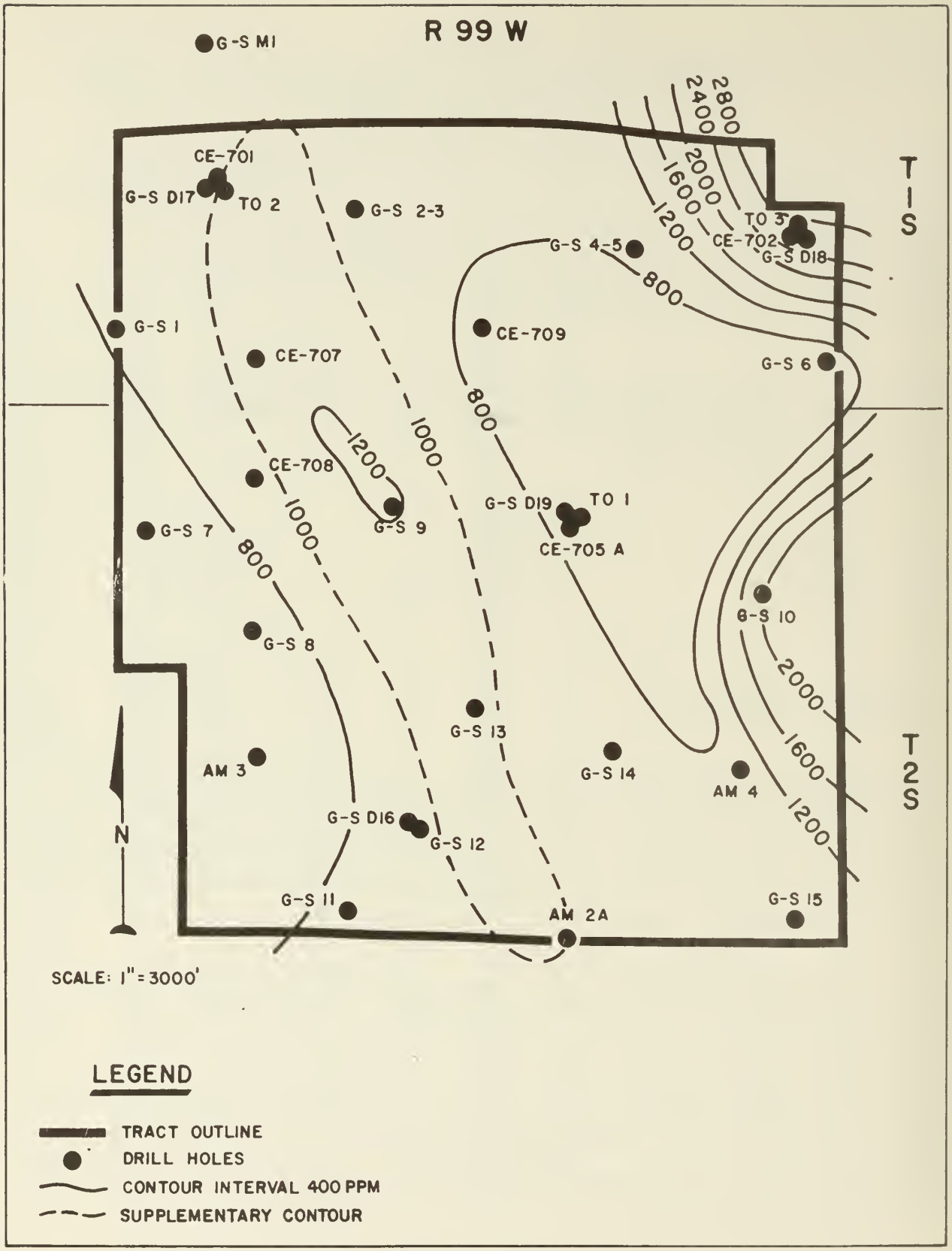


Figure 3-4-18

UPPER AQUIFER TOTAL DISSOLVED SOLIDS
AVERAGE OF MARCH THROUGH JULY 1975

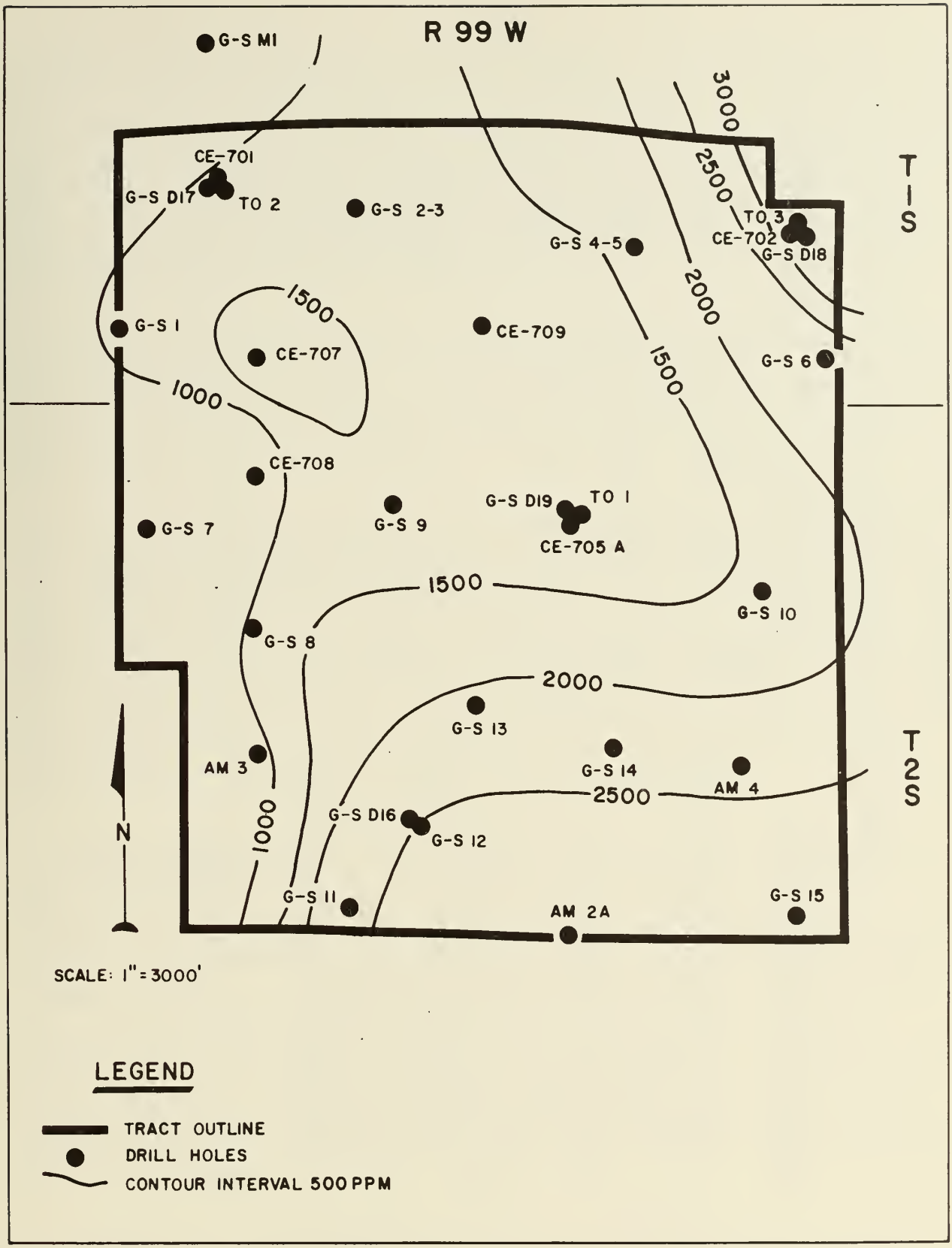


Figure 3-4-19

LOWER AQUIFER TOTAL DISSOLVED SOLIDS
AVERAGE MARCH THROUGH JULY 1975

Table 3-4-16

SUMMARY OF PRECIPITATION DATA FOR 1975

Storage-Type Rain Gage Locations	Monthly (inches)			Annual (inches)
	Max	Min	Avg	
1. Dry Fork near west line Tract C-a	1.95	0.23	0.78	9.41*
2. Box Elder Gulch near west line Tract C-a	2.04	0.26	0.90	10.84*
3. Corral Gulch near west line Tract C-a	2.1	0.23	0.85	10.16*
Recording-Type Rain Gage Locations				
4. Stake Springs Draw near confluence with Corral Gulch	2.43	0.06	1.22	14.65
5. Yellow Creek near White River	1.91	0.04	1.01	12.10
6. Cathedral Bluffs located in NW¼, NW¼, Sec. 14, T2S, R100W	2.49	0.43	1.45	17.38

*Includes 10% upward adjustment to account for estimated evaporation loss.

Two basic weather systems effect the precipitation. The frontal system generally results in widespread, uniform precipitation. The convection system or thunderstorm results in erratic precipitation amounts over an area of a few square miles. The duration of the frontal system precipitation could be a week or so. The thunderstorm duration is usually measured in minutes or hours. The heaviest precipitation to date appears to result from the thunderstorms rather than the frontal system.

Figure 3-4-20 is a chart for forecasting the rainfall frequency, duration and amounts expected in the Tract C-a area. Because of the lack of long-term data in the tract area, its use should be of help in predicting unusual precipitation events.

The July 9, 1975, storm recorded by the Stake Springs Draw recording station, indicates heavy precipitation for short periods of time. Figure 3-4-20 shows that the July 9 storm was an event that has a two- to five-year frequency. A total of 1.19 inches fell during a thirteen-hour period. This storm also produced the highest intensity with 0.16 inches and 0.25 inches during a five and ten minute period respectively. During a forty-five minute period, 0.51 inches was recorded, which was the largest single continuous precipitation event during the 12 months of data for all of the stations.

B. Springs and Seeps - The spring and seep locations shown on Figure 3-4-21 were located by NUS in the field. Some of these springs are perennially flowing, which, in conjunction with the geologic structure, indicates that the springs shown by the solid triangles are probably partially fed by the deep oil shale aquifers via fault zone conduits or joint-fracture systems. In order to further identify the source water of springs and seeps, the water sample analyses were studied. However, the results based on the water chemistry were inconclusive. The remaining intermittent springs are probably fed by perched aquifers or by the alluvium. Water quality summaries may be found in Section 3, Chapter 8.

C. Streams - All of the streams on Tract C-a can be classified as intermittent; however, some reaches are perennial. The majority of the streams in the

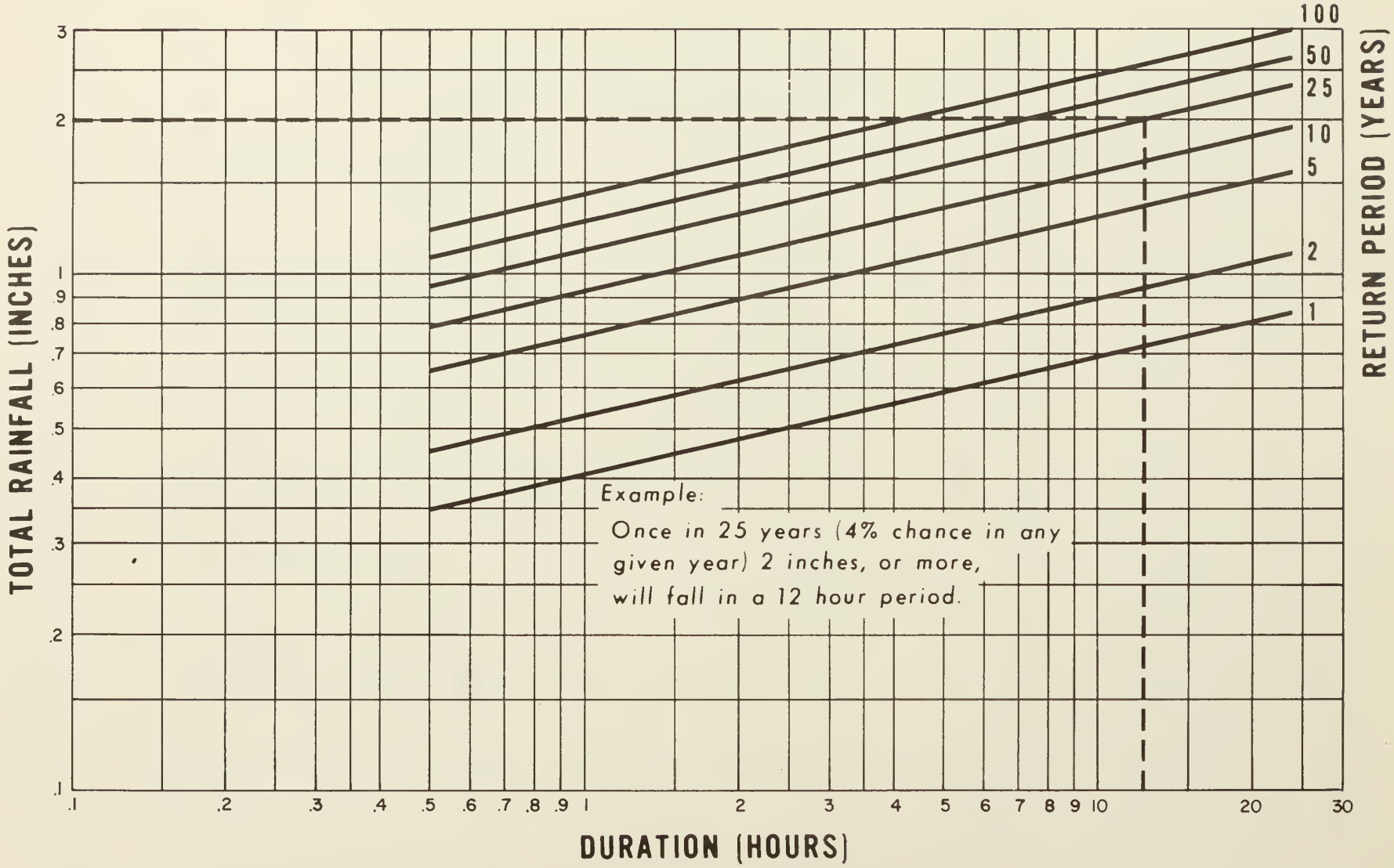


Figure 3-4-20

RAINFALL (DEPTH-DURATION-FREQUENCY) DIAGRAM FOR TRACT C-a VICINITY
FROM U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
TECHNICAL PAPER NO. 40

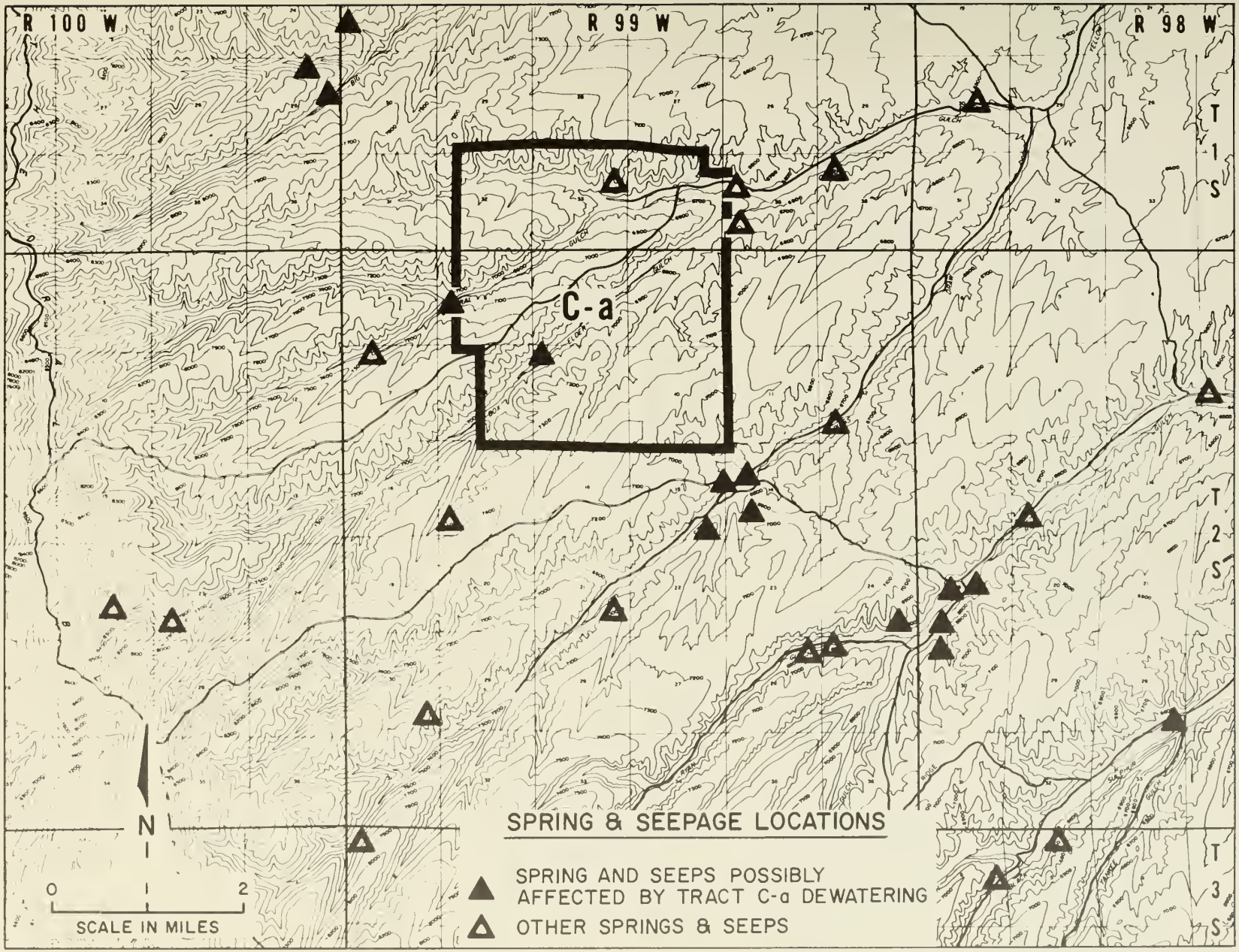


Figure 3-4-21

MAP OF SPRINGS AND SEEPS POSSIBLY AFFECTED BY TRACT C-a DEWATERING

Piceance Creek basin are ephemeral, i.e., only flow in response to precipitation and not to snowmelt runoff or springs and seeps. However, the maximum stream flow and sediment discharge in the vicinity of Tract C-a occur during snowmelt runoff as indicated by the data. While the 1974 runoff occurred during April and May, the 1975 runoff occurred during May and June. Although approximately equal, the 1975 peak runoff was slightly less than that of 1974 in the Tract C-a area.

The perennially flowing stream reaches in the vicinity of Tract C-a are the result of springs. There are only two perennially flowing reaches on Tract C-a. They are: in Corral Gulch near the western tract boundary which has approximately 1/3 cfs average flow and in Box Elder Gulch. However, the minimum low flow coming from spring sources just west of Tract C-a is less than 0.1 cfs.

Both Corral Gulch and Box Elder Gulch generally have some flow leaving Tract C-a. The Corral Gulch gaging station, approximately 1/2 mile east of Tract C-a, has an average annual flow of approximately 1 cfs. The mean low flow is approximately 0.4 cfs.

The gaging station at the mouth of Yellow Creek appears to have slightly different flow characteristics than the streams on and in the vicinity of Tract C-a. The average mean flow is approximately 1.8 cfs. The periods of sustained high flow are recorded during the winter and early spring months and appear to be related to snowmelt runoff.

Yellow Creek has a base flow of approximately 0.7 cfs with a dissolved solids content in excess of 3,500 mg/l, indicating a water source other than the surface system. It has been proposed by the USGS - WRD and others that the perennial flows in the lower reaches of Yellow Creek, the entire length of Piceance Creek, and the lower reaches of Black Sulphur Creek, are due to contributions by the deep ground water aquifers. The data collected at the Yellow Creek gaging station during the past year tend to indicate that this is the case.

A comparison of the water flows and quality are shown on Figure 3-4-22 for Corral Gulch and Yellow Creek near the White River. Bicarbonate is the predominant ionic constituent in the water as shown on Table 3-4-17. The average water quality at the three surface gaging stations near Tract C-a indicates that most of the constituents are below U.S. Public Health Service (USPHS) limits for potable water. However, the average water quality at the Yellow Creek station indicates the water exceeds the USPHS recommended limits for fluoride, iron, manganese, sulfate and dissolved solids.

D. Alluvial Aquifers - The alluvium in the vicinity of Tract C-a has been mapped by Trollinger Geological Associates, Inc. This mapping project only indicated the presence or absence of alluvium. The alluvial drilling program determined the depth of the alluvium and whether or not water was present in the alluvium as shown on Figure 3-4-23. The results of the alluvial monitoring program indicate that the major drainage systems have water-saturated alluvium and that in many of the minor drainage systems the alluvium is dry. In the major drainage systems the data indicate a seasonal trend in the water levels. This trend shows rising water levels during the snowmelt runoff period and declining water levels the remainder of the year. The limited observations to date from the continuous water level records indicate that the alluvial aquifers respond only indirectly to regional and local precipitation events.

The water quality in the alluvium tends to be generally poorer than the water quality of the surface stream. In Corral and Box Elder Gulches near the west tract boundary, the average dissolved solids in alluvium water are 150 mg/l greater than in the surface water at the gaging station. These averages are approximately 800 mg/l for the alluvium and 600-700 mg/l for the surface water. In the alluvium at Corral Gulch east of the tract, the alluvium has an average dissolved solids of 1,500 mg/l compared with 800 mg/l for the surface water at the gaging station.

Pumping tests have not been conducted in the alluvium; therefore, the aquifer characteristics are relatively unknown. However, it is anticipated from the nature of the alluvial material that the permeabilities and porosities would

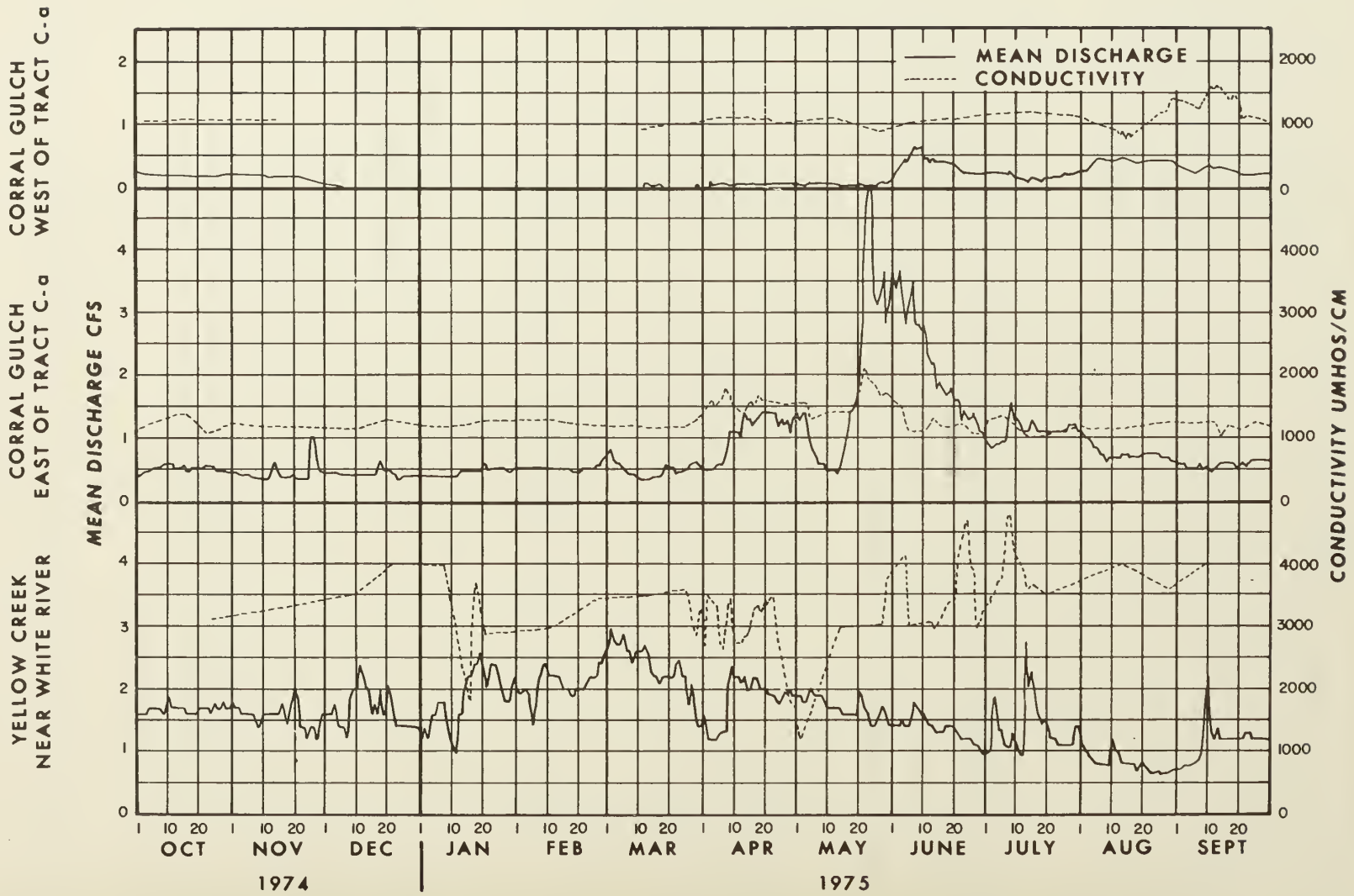


Figure 3-4-22

COMPARISON OF STREAM DISCHARGE AND CONDUCTIVITY

Table 3-4-17

COMPARISON OF AVERAGE WATER QUALITIES IN MG/L
THROUGH JULY, 1975

	STREAM FLOWS				SUBSURFACE AQUIFERS			USPHS LIMITS		
	BOX ELDER GULCH WEST TR C-a	CORRAL GULCH NEAR WESTLINE TR C-a	CORRAL GULCH EAST OF TR C-a	YELLOW CREEK NEAR WHITE RIVER	ALLUVIAL AQUIFERS	UPPER AQUIFER	LOWER AQUIFER	REC	MAX	COMMENT
ALKALINITY	291.78	321.061	422.34	1358.74	469.308	515.561	929.086			GENERALLY NOT HARMFUL
ARSENIC	0.007	0.005	0.005	0.005	0	0.004	.001	0.01	0.05	POISONING
BARIUM	0.070	0.033	0.021	0.170	0	0	0		1.0	POISONING
BICARBONATE	355.78	391.515	515.00	1408.54	566.735	607.246	1082.208			TASTE
CAOMIUM	0.001	0.001	0.001	0.001	0.009	0.002	0.001		0.01	POISONING
CALCIUM	70.44	84.82	83.83	33.83	99.163	69.279	42.120			HARONESS
CARBONATE	0	0	0	122.00	5.510	36.312	98.498			TASTE
CHLORIOE	5.88	7.588	9.73	102.45	17.698	26.287	35.704	250.0		TASTE & LAXATIVE PROP.
CHROMIUM	0.004	0	0.001	0.001	0	0.006	0		0.05	POISONING
COPPER	0.006	0.004	0.003	0.03	0.033	0.028	0.018	1.0		TASTE
CYANIOE	0.005	0.004	0.005	0	0.001	0	0	0.01	0.2	POISONING
FLUORIOE	0.40	0.33	0.92	2.06	0.333	4.299	13.547	0.8–1.7	1.4–2.4	MOTTLING OF TEETH
HARONESS	374.44	453.23	462.44	543.79	570.816	380.929	258.632			ECONOMICS,HEALTH
IRON	0.083	0.072	0.051	0.070	8.018	3.231	2.763	0.3		STAINING, TASTE
LEAD	0.003	0.0011	0.003	0.003	0.214	0.320	0.636		0.05	POISONING
MAGNESIUM	48.00	58.62	61.44	108.00	94.939	50.781	37.986			LAXATIVE
MANGANESE	0.006	0.012	0.020	0.024	2.298	0.114	0.057	0.05		STAINING, TASTE
NITRATE	0.93	0.87	1.65	1.29	5.106	0.514	0.810	45.0		METHEMOGLOBINEMIA IN INFANTS(BLUE BABIES)
SELENIUM	0.004	0.004	0.003	0.002	0	0	0		0.01	POISONING
SILICA	22.78	20.36	20.88	10.43	32.327	25.322	11.772			GENERALLY NOT HARMFUL
SILVER	0	0	0	0	0.003	0.008	0.004		0.05	POISONING- DISCOLORATION OF MEMBRANES
SOOIUM	56.78	84.73	121.54	730.00	191.531	273.000	534.024			HEART CONOITIONS
SULFATE	172.22	278.23	278.78	562.41	423.877	331.404	229.021	250.0		LAXATIVE & TASTE PROP.
OISSOLVEO SOLIDS	558.33	734.12	835.54	2396.07	1134.592	1150.743	1589.383	500.0		LAXATIVE, TASTE
ZINC	0.016	0.042	0.023	0.018	0.625	0.687	1.387	5.0		TASTE
RADIUM-226	0	0	0.07	0	0.256	0.215	0.476		3.0 pc/1	POISONING
STRONTIUM-90	1.000	1.500	1.633	3.550	0.100	0.177	0.147		10.0 pc/1	POISONING

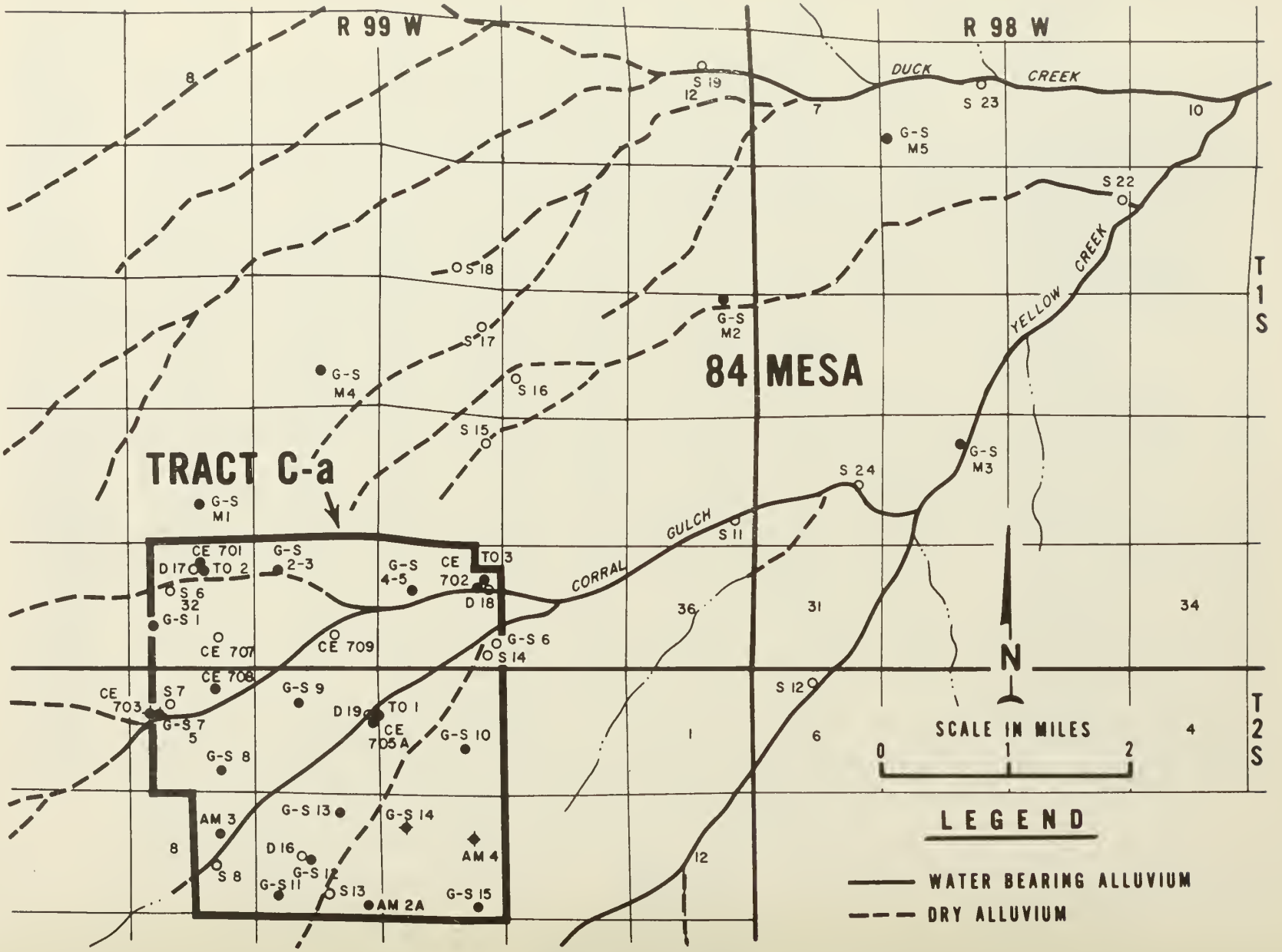


Figure 3-4-23

ALLUVIAL MAP TRACT C-a AND VICINITY

be relatively low. During the pumping tests conducted in the deep oil shale aquifers no measureable hydrologic connection between the alluvial aquifers and the deep oil shale aquifers were noted.

E. Deep Oil Shale Aquifers - The drilling programs indicated two major oil shale aquifer systems to be present under Tract C-a as shown on Figure 3-4-8. The upper aquifer system occurs in the vicinity of the Mahogany zone. The lower aquifer system is associated with the R-3 zone and in some cases is as deep as the Blue marker. Both aquifer systems are artesian. With the exception of the northeast corner of Tract C-a, the upper aquifer system has a higher potentiometric level than the lower aquifer system. On the average, the difference between the potentiometric levels is approximately 150 feet. Although quite variable from place to place the aquifers each have an average thickness of about 220 feet.

The water quality data obtained from the drilling program was found to have higher dissolved solids than the samples collected from either the pumping tests or the monitoring program. It is believed that this difference is due to the drilling process; i.e., the grinding up of the rock formation, thereby creating greater surface area. This, in addition to the agitation caused by the air lifting, caused more of the soluble minerals in the formation to go into solution.

The interpretation of the informal pumping tests conducted during the drilling operation resulted in higher transmissivities than the interpretation of the formal pumping tests. There are two explanations, both of which have a bearing on these higher values. The first is that the two aquifers were interconnected during the informal tests. The second explanation is similar to the reason for the higher transmissivity values obtained during the recovery portion of the formal pumping tests. As a result of the two aquifers being interconnected, artificial mounds and depressions were created in the lower and upper aquifers, respectively. Therefore, the aquifer response to the man-made stresses during the informal testing resulted in anomalous results; i.e., the transmissivities are greater than those found under more controlled conditions.

The completion program which consisted of isolating the two aquifer systems in and around Tract C-a was successful with the exception of the NE corner of the tract. At this location, an interconnection between the upper and lower aquifer systems still exists. This interconnection may be the result of faults in the area, inadequate isolation of the two aquifers in one of the three holes located in the NE corner of the tract and/or possible man-made fracturing as a result of experimental fracturing work done by WRD-USGS in 1973. It is not known at this time which of the above explanations should be considered the more viable.

As a result of the interconnection between the two aquifer systems via known open wells since as early as 1971, it is estimated that approximately 5,000 acre-feet of water flowed from the upper aquifer system to the lower aquifer system prior to October 1974. This value was calculated using 100 gpm from the spinner logs, as the average flow rate for the time each of the holes were open to both aquifers. This compares with approximately 145 acre-feet of water produced from the lower aquifer system during the RBOSP pumping test program and 30 acre-feet of water from the upper aquifer pumping tests. At present time all of the holes on and around Tract C-a have been completed in such a manner as to eliminate this mode of communication between the two aquifer systems.

The long-term pumping tests allowed for the calculation of transmissivity and coefficients of storage at various monitoring holes located on and around the tract. The extrapolation of these values resulted in apparent transmissivities of 2,500 gpd/ft. and 7,000 gpd/ft. for the upper and lower aquifers, respectively. It should be noted that the upper aquifer system responded only locally to stresses created during pumping while the lower aquifer system responded over a large area from single pumping tests. Therefore, the transmissivity and coefficients of storage for the lower aquifer system are considered to be much more reliable than those for the upper aquifer system.

The above transmissivities are generally lower than the average values derived from the drilling and pumping test programs. The upper aquifer average values varied from 2,200 gpd/ft. to 15,316 gpd/ft. The value of 2,500 gpd/ft. is

based on the small area affected by pumping the upper aquifer, indicating lower transmissivities than those measured at the pumped hole. In addition, the faults appear to act as barriers to flow in the upper aquifer. The lower aquifer transmissivities were also variable. They ranged from 9,600 gpd/ft. to 17,000 gpd/ft. The value of 9,600 was replaced because the pumping tests evaluation indicated lower values than those actually calculated. Thus, the average of 9,600 gpd/ft. was reduced to 7,000 gpd/ft. It should be noted that the lower aquifer pumping tests did not show any evidence of fault influence at that depth suggesting they die out with depth.

Calculations were made to determine the leakance value between aquifers. With the exception of the CE 705-A upper aquifer pumping test, values for leakance could not be derived. At this location two permeability values were derived. A value of 75 gpd/ft.^{2} was derived for the permeability between the upper and lower aquifer systems. The second possibility is that unobserved leakance occurred between the alluvial aquifer and the upper aquifer system. A value of 25 gpd/ft.^{2} was derived. It is anticipated that leakance occurred during all of the pumping tests but that the background water level due to the interconnection of the two aquifers prior to the pumping tests prevents a reasonable determination of the leakance value.

An analysis of the various pumping tests in both aquifer systems revealed an elongation of the cone of depression along the NNW-SSE axis. A comparison of the trends of the major fracture-joint sets on Tract C-a indicate three major directions. These are generally oriented NW-SE, SE-SW, and N-S. The directions are given in order of decreasing number of fracture and joint orientations. Therefore, a resultant preferred directional flow in these aquifers would be along the NNW-SSE as observed during the pumping tests and shown on Figures 3-4-24 and 3-4-25.

As indicated by the results of the pumping tests conducted in G-S 12, it appears that some of the faults act as barriers to water movement in the upper aquifer systems as shown in Figure 3-4-24. It appears highly possible that the upper aquifer system may respond to dewatering in a manner similar to an aquifer which has been divided into cells that are only partially connected hydrologically.

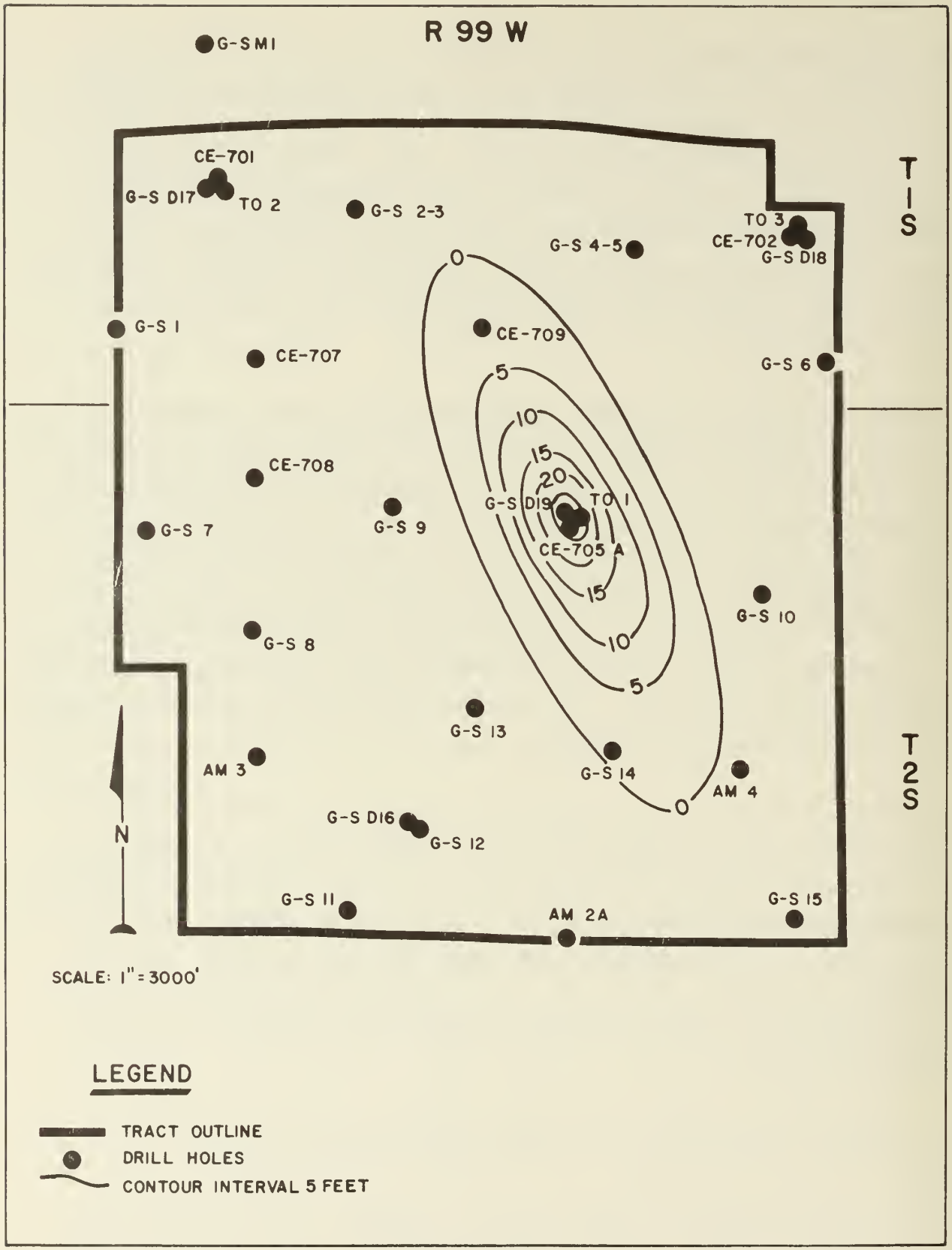


Figure 3-4-24

UPPER AQUIFER PUMPING TEST CE 705-A DRAWDOWN
AT APPROXIMATELY 3,000 MINUTES

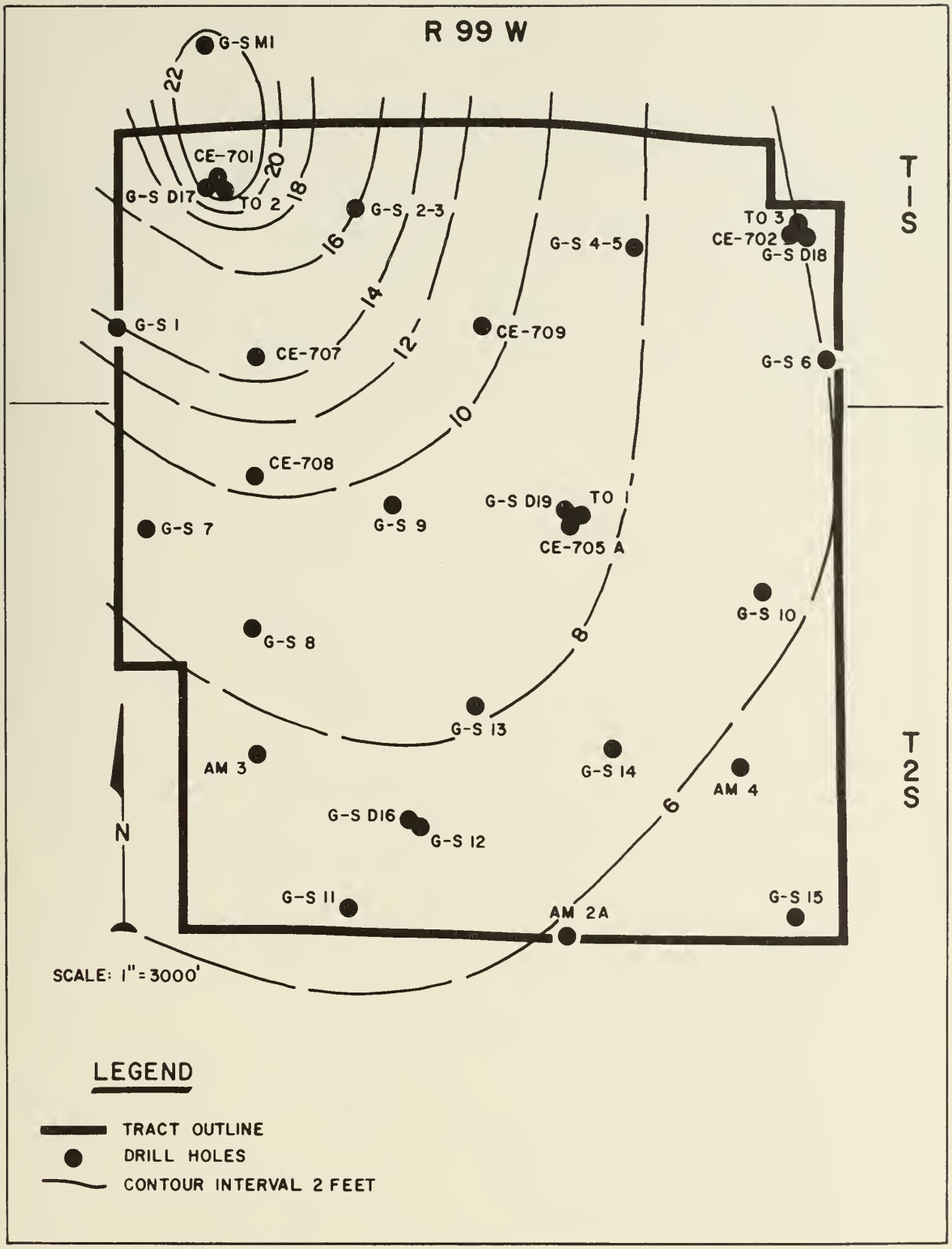


Figure 3-4-25

LOWER AQUIFER PUMPING TEST G-S D17 DRAWDOWN
AT APPROXIMATELY 21,500 MINUTES

An areal plot of upper and lower aquifer thickness, transmissivities and permeabilities are shown in Figures 3-4-26 to 3-4-31. Transmissivities are based on pumping test weighted averages that were derived assuming standard non-leaky Theis and Jacob theoretical conditions. Aquifer thicknesses were derived from information gained during drilling, such as drilling water quality analysis, production logging, etc. With aquifer thickness and transmissivity established, it is possible to derive formation permeability. This has been done for the lower aquifer (Figure 3-4-31). Due to the lack of data points for areal distribution for upper aquifer transmissivity, an area permeability map was not plotted. Thickness maps show substantial variation over the Tract. A general thickening trend could not be determined due to troughs and highs that finger into the tract area.

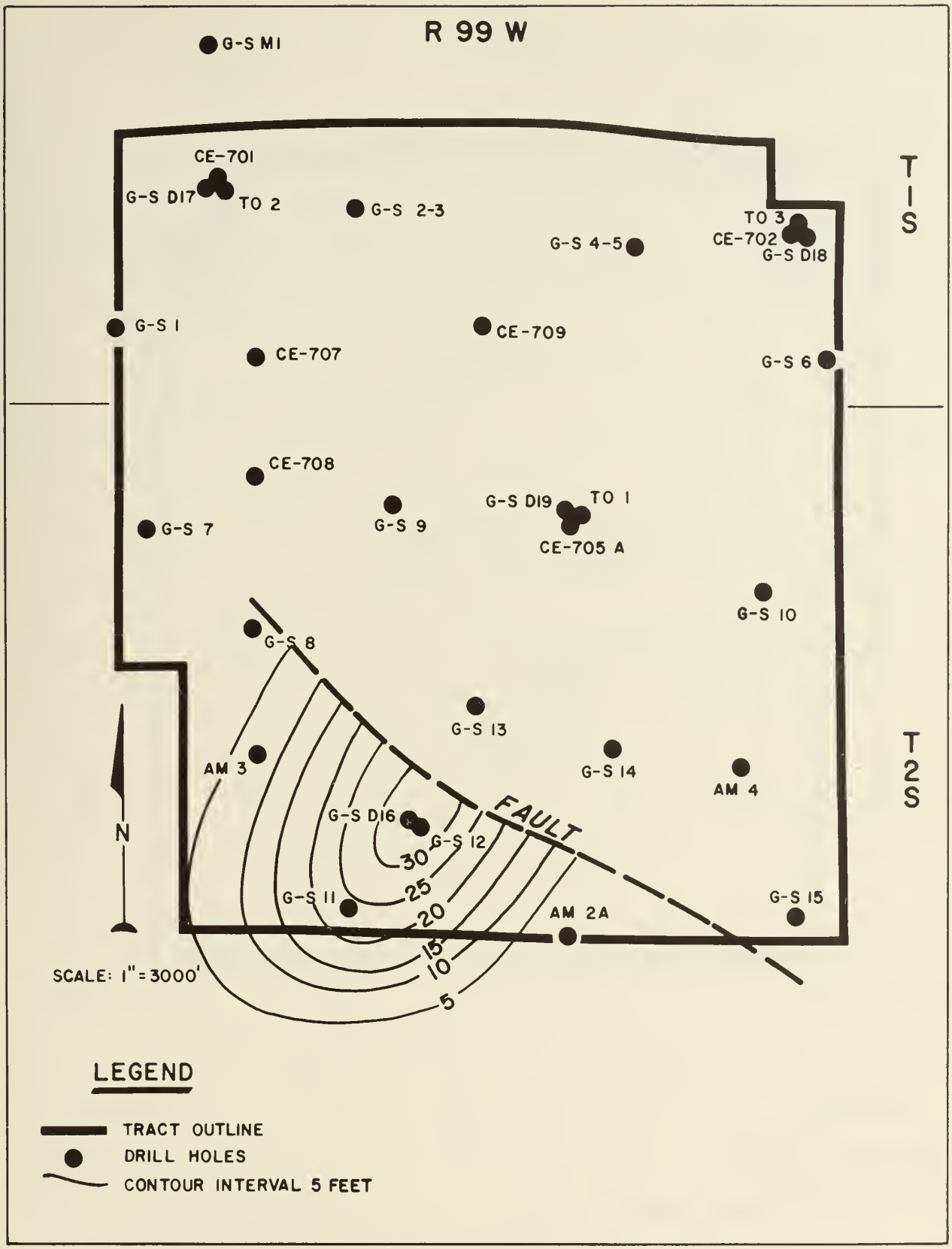


Figure 3-4-26

UPPER AQUIFER PUMPING TEST G-S 12 DRAWDOWN
AT APPROXIMATELY 13,000 MINUTES

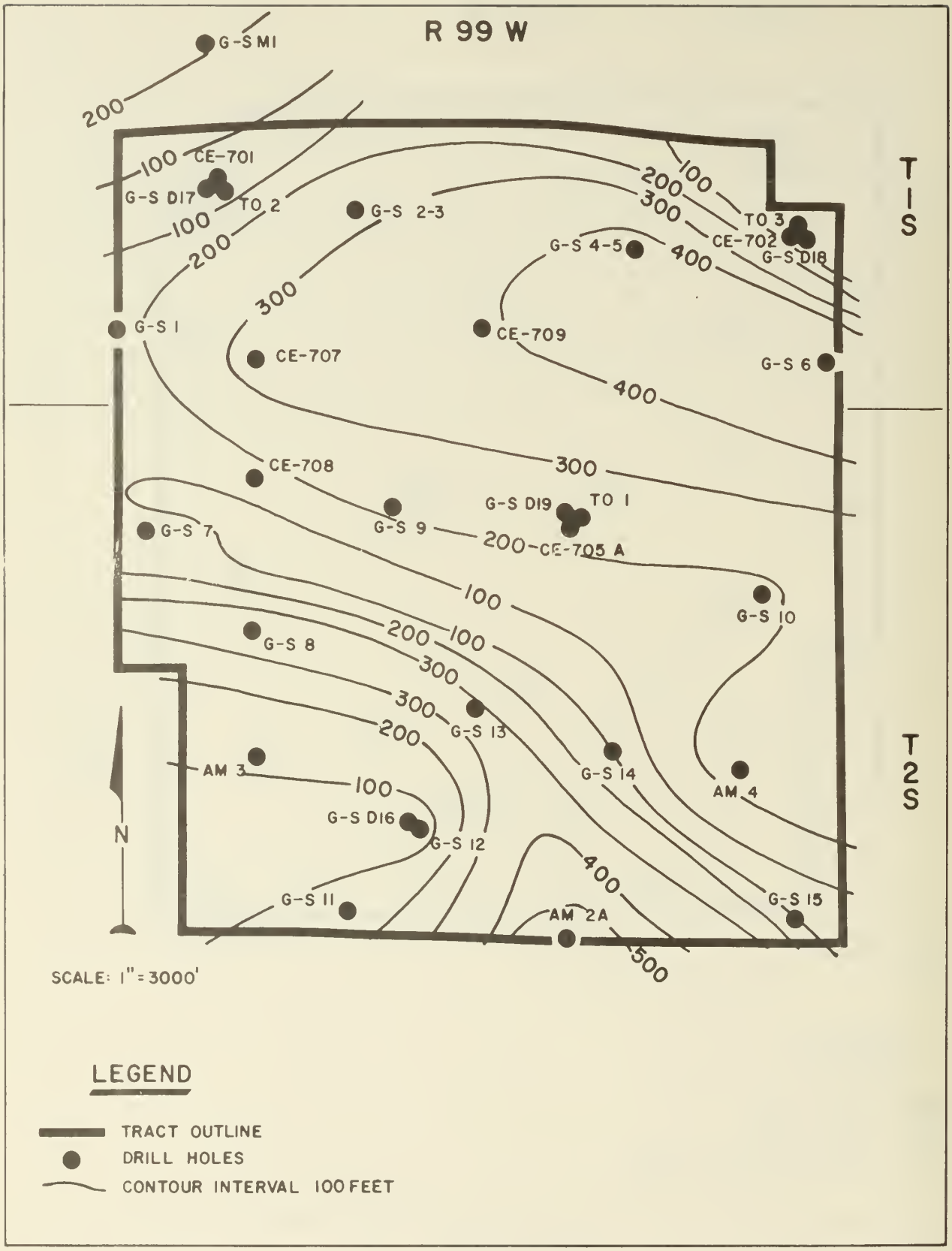


Figure 3-4-27

UPPER AQUIFER THICKNESS (ft)

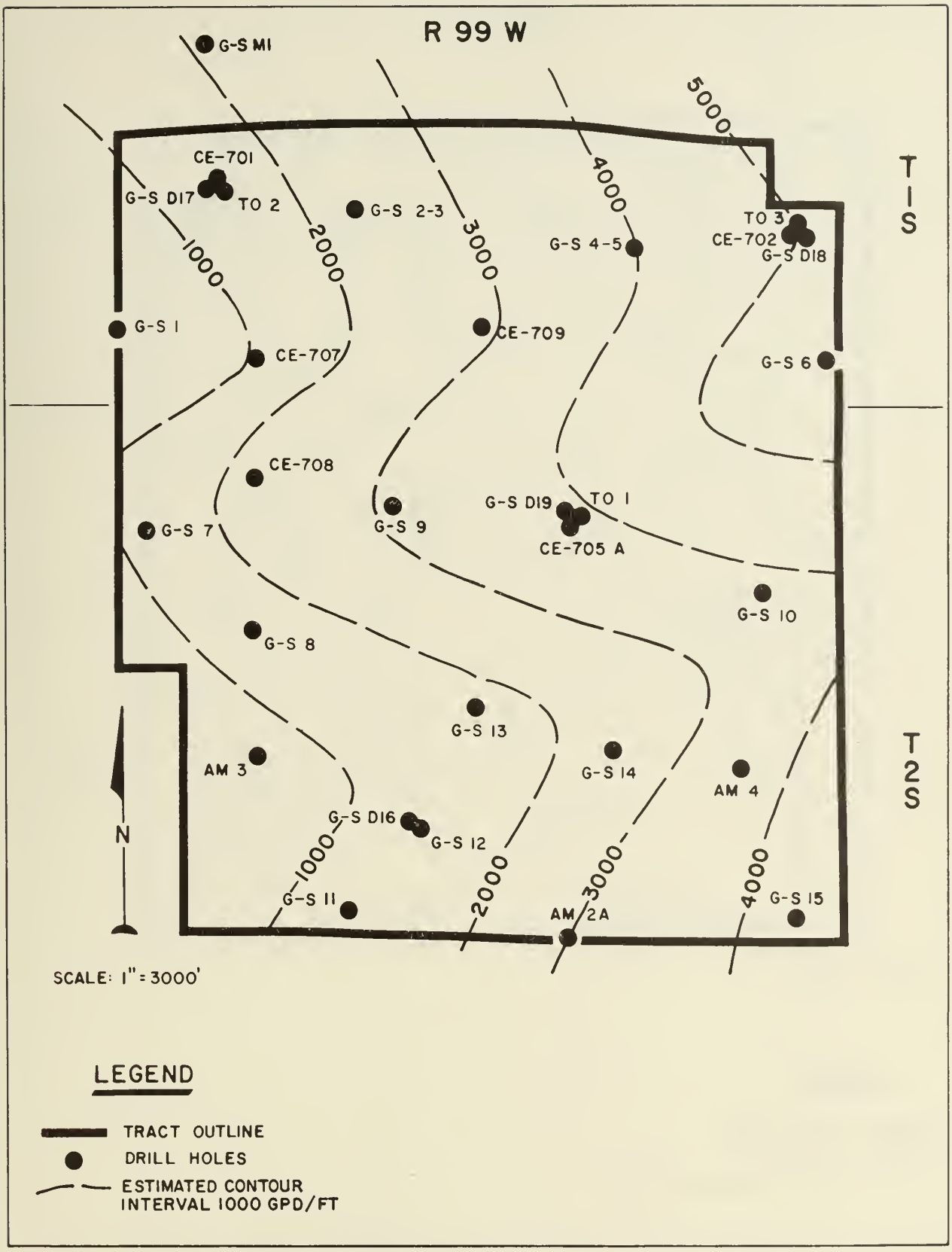


Figure 3-4-28

UPPER AQUIFER APPARENT TRANSMISSIVITY (gpd/ft)

3-4-83

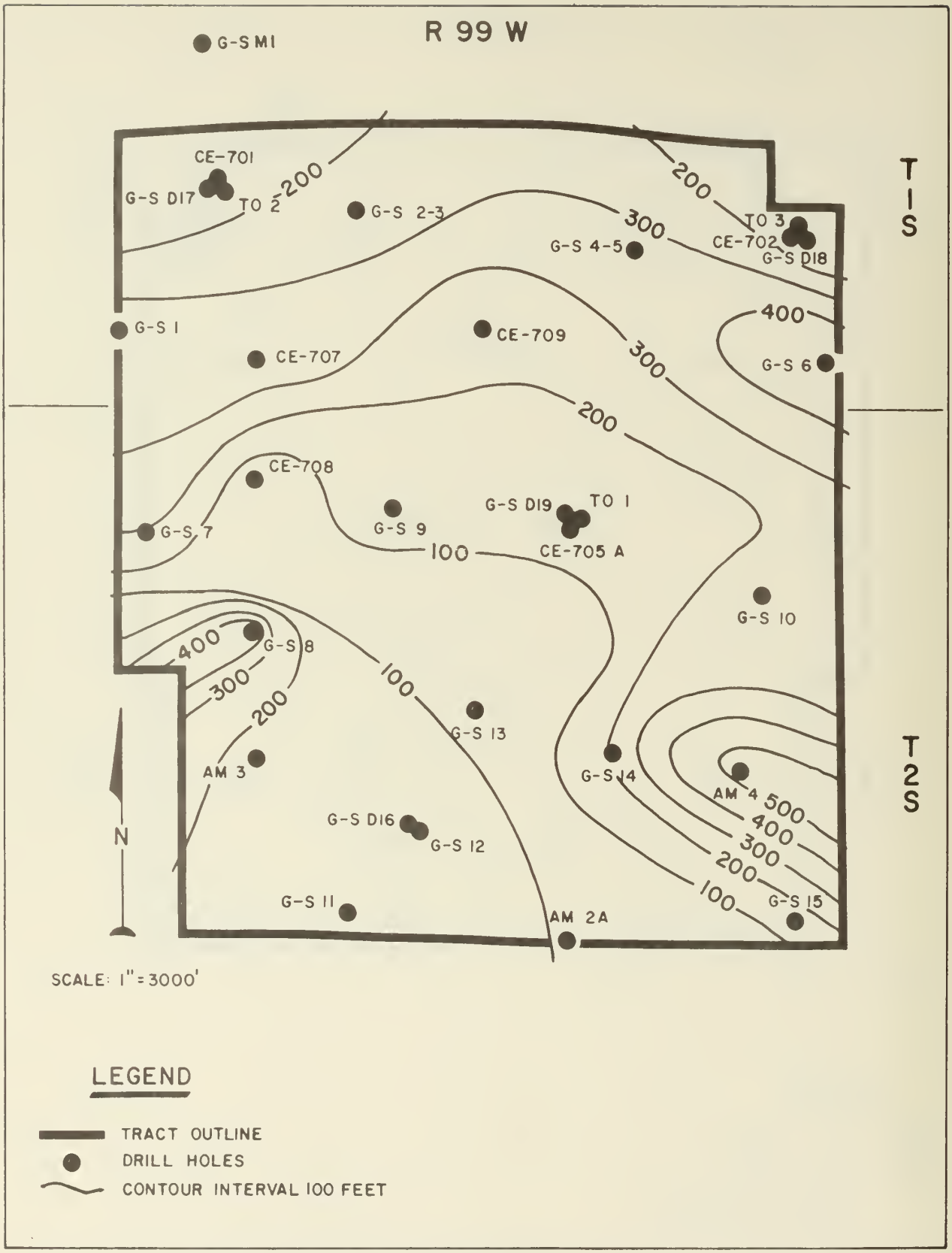


Figure 3-4-29

LOWER AQUIFER THICKNESS (ft)

3-4-84

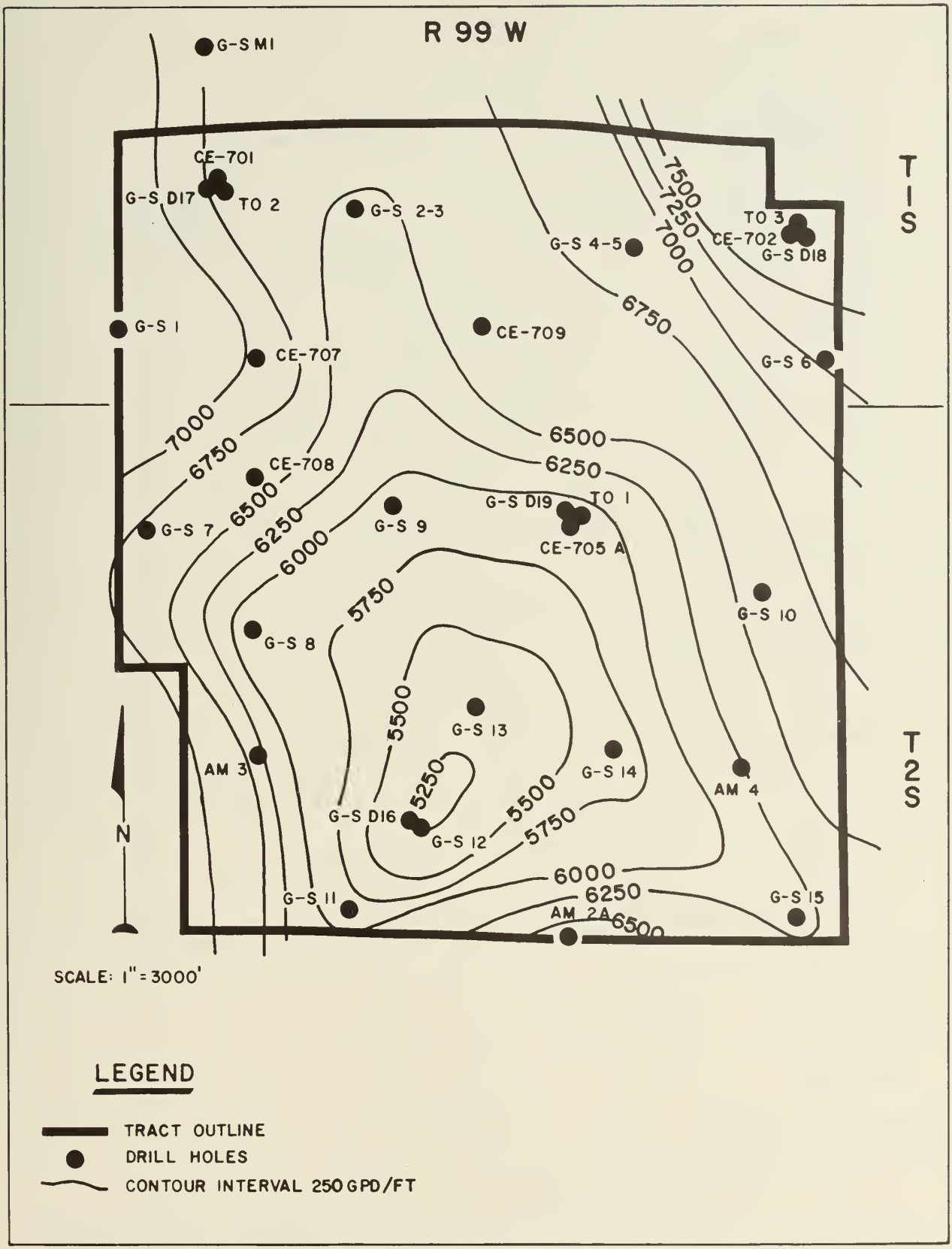


Figure 3-4-30

LOWER AQUIFER TRANSMISSIVITY (gpd/ft)

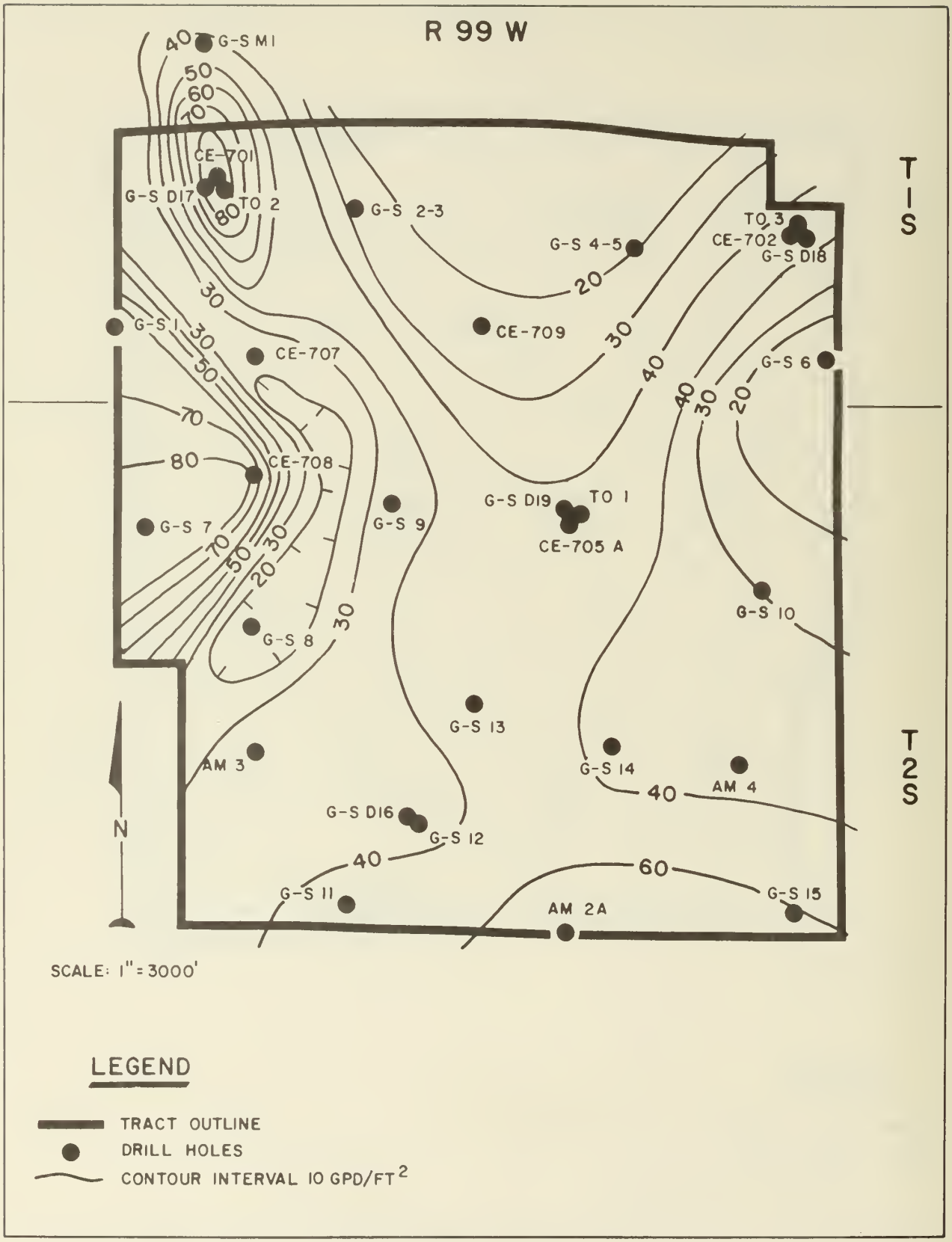


Figure 3-4-31

LOWER AQUIFER PERMEABILITY (gpd/ft^2)

3-4-86

CHAPTER 5

AIR QUALITY

SECTION 3
BASELINE CONDITIONS

Air quality measurements are taken at four sites in the vicinity of Tract C-a (Figure 3-5-1). The baseline air quality program involves the measurement of sulfur dioxide, hydrogen sulfide, methane, total hydrocarbons, nitric oxide, total oxides of nitrogen, carbon monoxide, ozone, particulates, and particulate size.

Percentage of data recovered for continuously monitored parameters have been computed and updated throughout the baseline data collection. This has been done to show the effort being made to satisfy the Oil Shale Lease Environmental Stipulations. These stipulations state that..."In the collection of baseline data, the Lessee shall monitor air quality over at least 90 percent of each lease year, during which monitoring is required, using four strategically-located stations." The annual, cummulative data recovery percentage by type of air quality parameter are presented in Table 3-5-1.

The equation used to determine monthly data recovery percentages is given below.

$$\text{Monthly Percentage Recovered} = \left[\frac{\text{Actual Recovered Data (hours)}}{\text{Total Possible Recovered Data (hours)}}\right] X \left[100\%\right]$$

In this equation, Actual Recovered Data include:

- Data collected, processed and analyzed under quality assurance control;
- Data temporally bracketed by routine calibration data;
- Calibration periods: Although recorded data are not available for analysis or use as part of the baseline data, the recovery rates are not penalized for critical calibration time. Therefore, calibration hours are included as a portion of the actual recovered

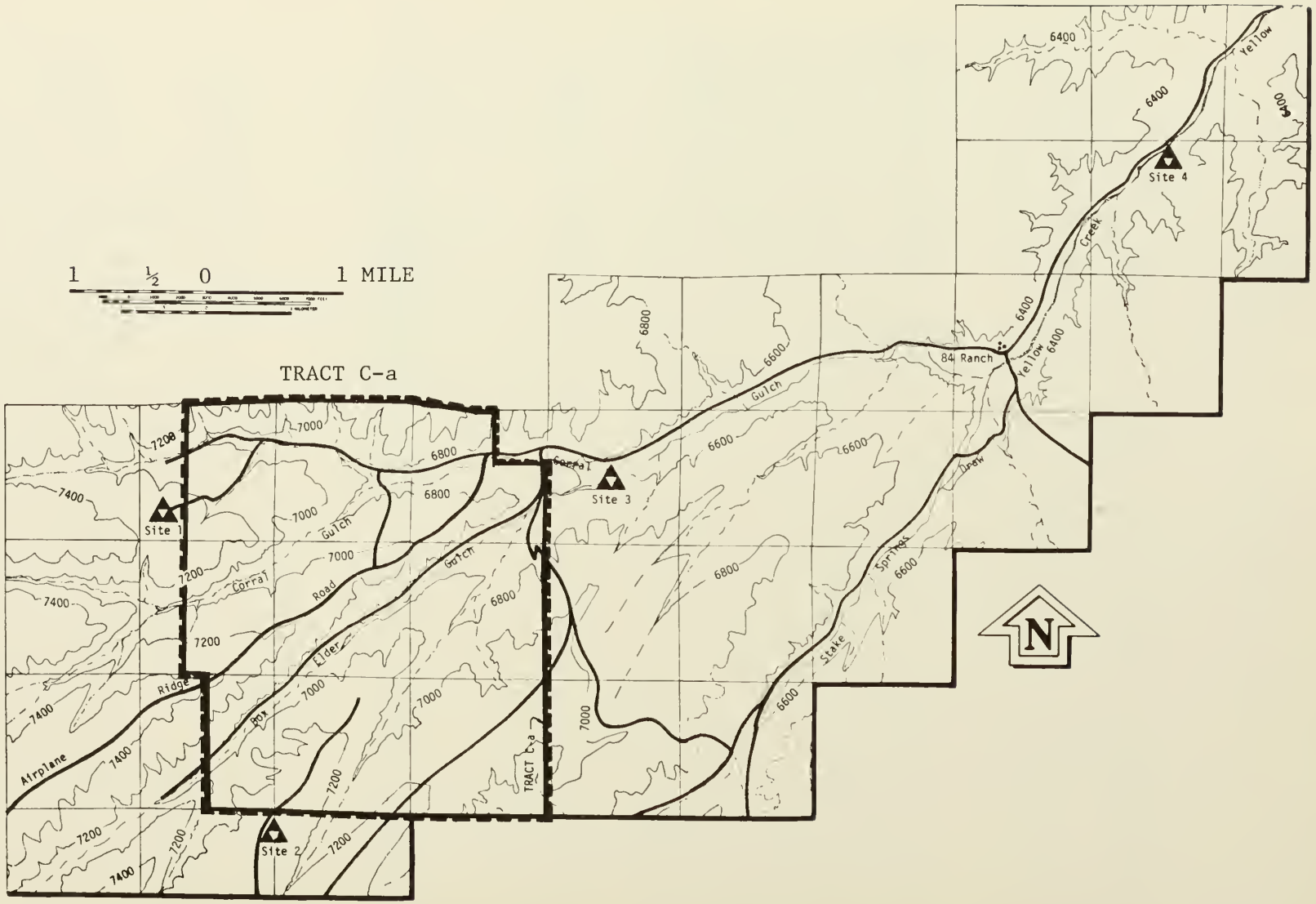


Figure 3-5-1
TOPOGRAPHIC MAP OF AREA AROUND TRACT C-a SHOWING
LOCATIONS OF METEOROLOGICAL/AIR QUALITY STATIONS

Table 3-5-1

AIR QUALITY ANNUAL CUMULATIVE
PERCENTAGE RECOVERED*
(1 FEBRUARY 1975 THROUGH 31 JANUARY 1976)
RBOSP

Parameter	Percent**
High Volume Sampler (HVS)	93.5
Sulfur Dioxide (SO_2)	94.7
Hydrogen Sulfide (H_2S)	90.5
Total Hydrocarbons (THC)	95.8
Methane (CH_4)	95.7
Carbon Monoxide (CO)	95.0
Ozone (O_3)	98.0
Nitrogen Oxide (NO)	96.7
Oxides of Nitrogen (NO_x)	96.7

* If the total instrument operational hours are used for the numerator in the equation for "Monthly Percentage Recovered", the percentages reported would be higher than those indicated.

** Annual goal: $\geq$ 90%

data hours;

Force Majeure Periods: Although data are not always reliably recorded during these periods, time of force majeure is included as actual recovered day(s). Force majeure is defined as those conditions that are not practically controllable or avoidable such as storms, lightning, snow, extreme winds, public power failures, or severe acts of God.

On a monthly basis, the "Monthly Percentage Recovered" is determined for each air quality and meteorological parameter and location combination using this equation.

From "Monthly Percentage Recovered" values a "Percentage Recovered Through the Month" has been calculated using the following equation:

$$\text{Percentage Recovered Through the Month} = \left[\frac{\left(\begin{array}{c}\%\text{ present}\\ \text{month*}\end{array}\right)\left(\begin{array}{c}\text{total days}\\ \text{present month}\end{array}\right)+\left(\begin{array}{c}\%\text{ through}\\ \text{previous}\\ \text{month}\end{array}\right)\left(\begin{array}{c}\text{total days}\\ \text{through}\\ \text{previous}\\ \text{month}\end{array}\right)}{\text{total days through present month}}\right] X \left[100\%\right]$$

* from equation for Monthly Percentage Recovered

The cumulative percentage by type of air quality parameter, for those sites and locations where the parameter is measured, is calculated by the following equation using the "Percentage Through the Month" values:

$$\text{Percentage Recovered By Type of Parameter} = \frac{\sum_{1}^{n^*} \text{Percentage Through the Month for Location } n^*}{n^*}$$

* n = numerical count of locations at which parameter is measured

These annual percentages in combination with the results of the quality assurance program satisfy the quality and quantity requirements of the Oil Shale Lease Environmental Stipulations.

Reliability of baseline air quality data is ensured by a comprehensive Quality Assurance program. Maintenance, operational, calibration, handling, shipping, storage, and inspection procedures are documented. Calibration procedures are traceable to established standards. Calibration schedules are established and rigorously executed. Quality Assurance audits are scheduled on a regular basis to monitor compliance with calibration and equipment maintenance procedures and other elements of the program. Discrepancies are documented and resolved. Any deviations are documented and affected data verified before being incorporated into the data base. The documentation system is program-wide and is continuously up-dated.

5.1 OBJECTIVES

Air Quality parameters are measured for the following reasons:

- To determine background concentrations prior to any major development on Tract C-a;
- To provide data for comparison of observed levels with prevailing and proposed Federal and State air quality standards;
- To aid in the interpretation and evaluation of diffusion model results (Section 9 Chapter 5);
- To satisfy the Oil Shale Lease Stipulations, 1974.

Descriptive information on site locations, instrumentation, maintenance and calibration procedures, the Quality Assurance program, and detailed data presentation can be found in one or more of the following documents: Progress Reports 2, 3, 4 (RBOSP, 1975a, 1975b), Progress Reports 5 and 6 (RBOSP, 1976b, 1976c), Annual Report (RBOSP, 1976a), and Statement of Work and Organization for Meteorological Systems, Air Quality Systems, and Studies (EG&G, Inc., 1974). Persons desiring further information should consult these documents which are on file with the AOSS in Grand Junction, Colorado.

5.2 METHODS

The air quality and meteorological data acquisition system for RBOSP consists of: four monitoring sites, each with tower-mounted meteorological instruments and trailer-contained air quality instrumentation; interface electronics; RF data telemetry links; and a central minicomputer at Site 1 for data storage and processing (Figure 3-5-2). Air quality parameters measured at each site are given below:

Site	Air Quality Parameter									
	THC	CH_4	SO_2	H_2S	NO_x	NO	CO	O_3	Particulates	Particulate Size
1	x	x	x	x	x	x	x	x	x	x
2	x	x	x	x					x	
3	x	x	x	x	x	x	x	x	x	
4	x	x	x	x					x	

The ambient air at each of the four sites is continuously sampled for gaseous parameter analysis through an air sampler intake located 10 ft above ground level. This intake is connected to a manifold which supplies air samples to each of the air quality gas-monitoring instruments. Data from each instrument are fed into the Site 1 processor (minicomputer). The minicomputer then performs necessary analyses, converts the information into engineering units, i.e., parts per million (ppm) values, and prints hourly averages of these values. The minicomputer also controls the storage of processed data on magnetic tape, the primary recording medium. Strip chart analog records are also made for each of the gaseous parameter measurements.

Particulates are sampled by a 24-hr period batch-sampling method. Sampling is performed every third day. At Site 1, size distribution of particulates is measured every twelfth day and samples are collected for quarterly trace element analysis of the particulates.

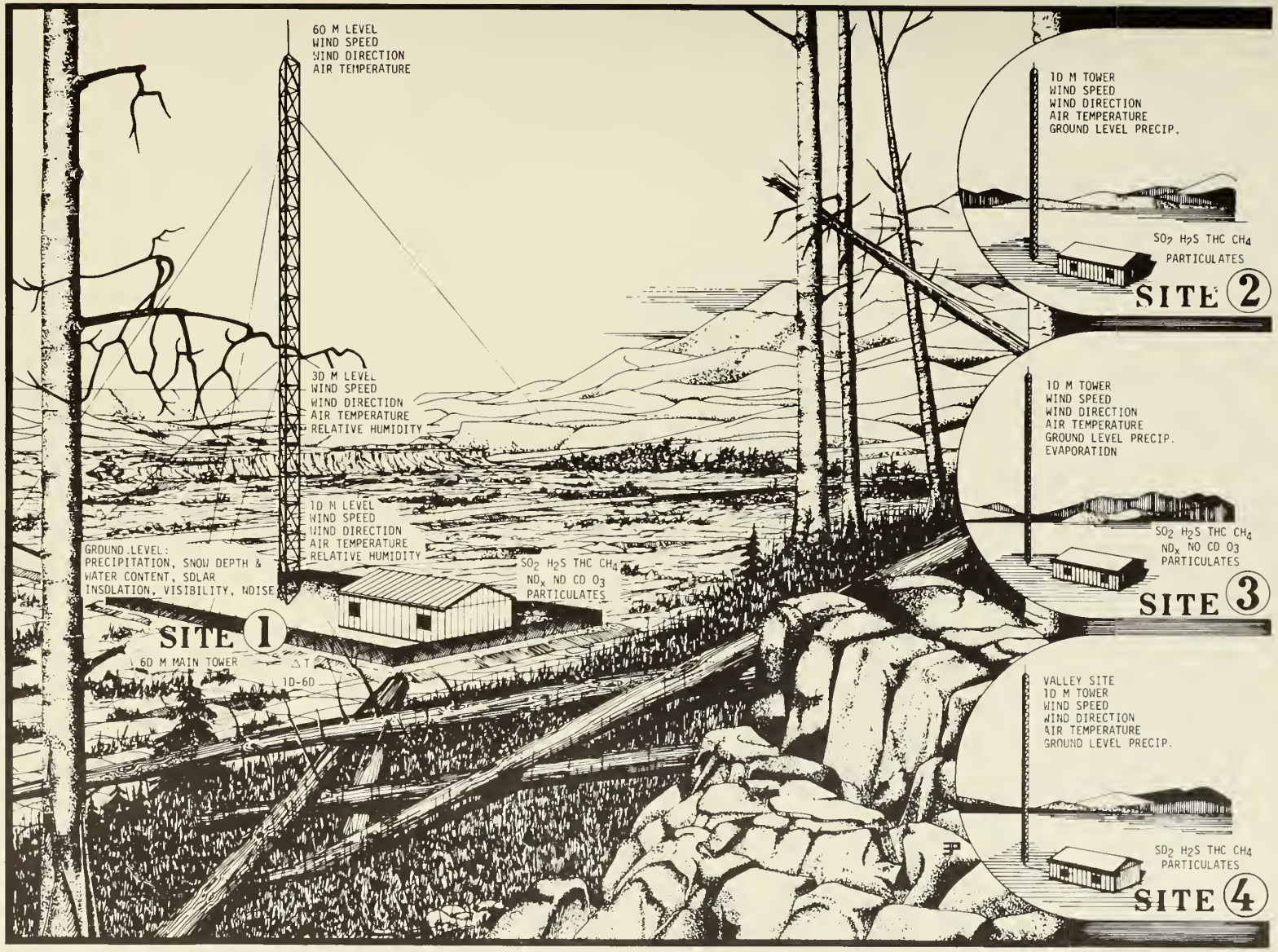


Figure 3-5-2

METEOROLOGICAL AND AIR QUALITY DATA
ACQUISITION SYSTEM FOR TRACT C-a, RBOSP

Continuously recorded data are averaged hourly. These averages are stored on magnetic tape. Averages, other than on an hourly basis, are developed by computations from the hourly averages. Data from particulate measurements are reduced manually and then entered into the computer system to be processed for the desired averages, e.g., geometric and arithmetic means.

Table 3-5-2 shows the instruments and air quality measurement techniques used for monitoring gases. Also presented are the lower detectable limits (LDL) for the instruments. The LDL is interpreted as the lowest concentration that can be differentiated from signal noise. Instrument outputs, however, are recorded to less than 0.001ppm. Particulate samples are collected using a high volume sampler which is calibrated to STP*. Detailed descriptions of the equipment and techniques used can be found in the progress and annual RBOSP reports previously cited.

*STP: Standard Temperature and Pressure

Table 3-5-2

AIR QUALITY INSTRUMENTATION AND MEASUREMENT TECHNIQUES,
RBOSP

Parameter	Manufacturer	Model	Technique	Lower Detectable Limit (ppm)[3]	Accuracy ± (ppm)
SO_2/H_2S	Bendix	8700X	Flame photometric with separation column for SO_2 and H_2S	0.005	0.020[3]
NO_x/NO	Bendix	8101-B	Chemiluminescence	0.005	0.010[3]
THC/CH_4	Bendix	8201	Flame ionization detector with separation column for CH_4	0.005	0.10 (THC)[3] 0.02 (CH_4)[3]
Photochemical Oxidant (O_3)[1]	Bendix	8002	Chemiluminescence	0.001	0.004[2]
CO	Bendix	8501-5CA	Nondispersive infrared detection	0.5	0.500[2]

[1] Photochemical oxidant corrected for interference due to nitrogen oxide and nitrogen dioxide as measured by the Federal Reference Method as Ozone (O_3) by the chemiluminescence method.

[2] Estimated accuracy (Bendix)

[3] Bendix Manual for instruments (1973a, 1973b, 1973c, 1973d, 1974)

5.3 LITERATURE REVIEW

A review was made of Federal and State air quality regulations to identify those pertinent for evaluating the background air quality measurements made on Tract C-a. Reports of investigations performed in the area around Tract C-a as well as Federal and State publications that deal with oil shale development were also reviewed to obtain additional information, especially concerning anticipated air quality impacts of oil shale development.

A. Federal and State Regulations - Development of Tract C-a is subject to Federal and State control and regulation. Some of the requirements are specific to oil shale development while others are general for control of air quality impacts from a wide range of sources. Federal and State regulations and stipulations which may be applicable during the development of Tract C-a are described below.

National Primary and Secondary Ambient Air Quality Standards, CFR 40, Part 50 (United States Environmental Protection Agency, 1971) - According to these regulations:..."National primary ambient air quality standards define levels of air quality which the Administrator judges are necessary, with an adequate margin of safety, to protect the public health. National secondary ambient air quality standards define levels of air quality which the Administrator judges necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant." Current standards for pollutants for which ambient air standards have been established are presented in Table 3-5-3.

Significant Deterioration of Air Quality, CFR 40, Part 52 (United States Environmental Protection Agency, 1974) - The EPA promulgated in 1974, at the direction of the courts, regulations to ensure that there is "no significant deterioration" in air quality in terms of SO_2 and suspended particulates for those areas of the country which do not presently exceed the National Ambient Air Quality Standards. Section 52.21 (c) of these regulations establishes the maximum allowable incremental concentration of a pollutant over existing background levels by area class designation. Three classes, I, II

Table 3-5-3

FEDERAL PRIMARY AND SECONDARY AMBIENT
AIR QUALITY STANDARDS (CFR 40 PART 50)

Substance	Standard ($\mu g/m^3$) Primary	Secondary
Sulfur Oxides		
Annual arithmetic mean	80	None
24-hour maximum*	365	None
3-hour maximum*	None	1,300
Particulates		
Annual geometric mean	75	60
24-hour maximum*	260	150
Carbon Monoxide		
8-hour maximum*	10,000	10,000
1-hour maximum*	40,000	40,000
Hydrocarbons		
3-hour maximum* (6-9 am)	160	160
NO_2		
Annual arithmetic mean	100	100
Photochemical Oxidant		
1-hour maximum*	160	160

*Not to be exceeded more than once per year

Source: United States Environmental Protection Agency, 1971

and III, are defined with all areas of the country presently being classified as Class II. Redesignations may be proposed by the applicable State or Federal Land Manager or Indian Governing Body having jurisdiction over the area to be redesignated. The maximum allowable incremental concentrations of pollutants for Class I and Class II areas are presented in Table 3-5-4. Class I areas are those considered pristene. Class III areas may not have increases in ambient air concentrations of SO_2 and suspended particulates which result in ambient concentrations greater than the National Ambient Air Quality Standards.

Oil Shale Lease and Environmental Stipulations (United States Bureau of Land Management, 1974) - Environmental stipulations were incorporated into the Tract C-a lease by the BLM to ensure that appropriate measures are taken to prevent pollution of the environment. These stipulations require environmental baseline monitoring, mitigating procedures, and operational monitoring to ensure that pollution is minimized and where possible avoided. Specifically relating to background monitoring the stipulations say:..."in the collection of baseline data, the Lessee shall monitor air quality over at least 90% of each lease year, during which monitoring is required, using four strategically-located stations. One of the stations shall be at the expected point of maximum concentrations, or as close to that expected point of maximum concentration as feasible. The Lessee shall monitor air quality for sulfur dioxide, hydrogen sulfide, and suspended particulates, using automatic instruments with continuous recorders, when applicable. The lessee shall also monitor, under the same conditions, hydrocarbons, oxides of nitrogen, and other pollutants, where the mining supervisor has determined that such monitoring is necessary to determine baseline air quality or to conduct an effective monitoring program."

Colorado Air Quality Control Regulations and Ambient Air Standards (Colorado Air Pollution Control Commission, 1970) - Tract C-a pollution control falls under the jurisdiction of the Colorado Air Pollution Control Commission of the Colorado Department of Health. The Piceance Creek Basin has been designated in the State of Colorado Implementation Plan as being in the Colorado-Utah Oil Shale Interstate Air Quality Maintenance Area. Through designation of

Table 3-5-4

MAXIMUM ALLOWABLE INCREMENTS OF SELECTED POLLUTANTS FOR AREA CLASSES AS ESTABLISHED BY SIGNIFICANT DETERIORATION REGULATIONS (CFR 40 PART 52)

Pollutant	Class I $\mu g/m^3$	Class II $\mu g/m^3$
Particulate matter:		
Annual geometric mean	5	10
24-hr maximum	10	30
Sulfur dioxide:		
Annual arithmetic mean	2	15
24-hr maximum	5	100
3-hr maximum	25	700

Class III area standards are not to exceed the National Air Quality Standards.

Source: United States Environmental Protection Agency, 1974

the entire region as a maintenance area, the State identifies it as having the potential for violation of particulates, SO_2, CO, or O_3 standards within the next 10 years. The State is divided into "designated" and "nondesignated" areas for suspended particulate matter. "Designated" areas are Air Quality Control Regions, which are primarily population and industrial centers. Other areas of the State, primarily rural, are considered "nondesignated" areas. The ambient air standards for designated and nondesignated areas for particulate matter are shown in Table 3-5-5.

Colorado Air Quality Control Regulations and Ambient Air Standards (Colorado Air Pollution Control Commission, 1975) - In 1975 the Colorado Air Pollution Control Commission promulgated regulations based on an incremental approach for controlling ambient levels of SO_2 in areas of the State. Area identifications are based on a modification of designated-nondesignated classifications. Areas that were formerly nondesignated areas are classified "Category I" in these regulations. These areas are allowed a limited increase in SO_2 concentrations over baseline SO_2 concentrations. Areas that were formerly designated areas are now classified "Category III." These areas can have the highest allowable SO_2 concentration above which no new source of SO_2 would be permitted. The incremental ambient air standards of SO_2 under these regulations are listed in Table 3-5-6. The Air Pollution Control Commission may consider redesignation of areas after receiving a request for redesignation and holding at least one public hearing in the affected area. Requests for redesignation shall, at a minimum, include information as to (1) growth anticipated in the area, (2) the social, environmental, and economic effects of such redesignation upon the area being proposed for redesignation, and (3) any impacts of such proposed redesignation upon regional, state, or national interests. This process provides the mechanism for an area to be designated a Category II area.

B. Studies and Reports - Numerous studies and reports have been done which investigate the development of oil shale and/or in which analysis of the potential impacts of oil shale development are presented. In addition, baseline studies have been done for the area around Tract C-a for similar develop-

Table 3-5-5

STATE OF COLORADO SUSPENDED PARTICULATE MATTER AMBIENT AIR STANDARDS FOR DESIGNATED AND NON-DESIGNATED AREAS

Suspended Particulate Matter[a]	Non-Designated Areas	Metro-Denver Air Quality Control Region, and Designated State Areas		
		1973	1976	1980
Short Term[b] ($\mu g/m^3$)	150	200	180	150
Long Term[c] ($\mu g/m^3$)	45	70	55	45

a. Measured at ambient conditions.
b. A 24-hour maximum of any 24-hour period and must not be exceeded more than once in a 12-month period.
c. Long Term Level- An annual arithmetic mean of all 24-hour concentrations.

Source: Colorado Air Pollution Control Commission, 1970

Table 3-5-6

STATE OF COLORADO SULFUR DIOXIDE
AMBIENT AIR STANDARDS, 1975

Averaging Intervals	Maximum Allowable SO_2 Increments Over Baseline				Maximum Allowable Concentrations of SO_2	
	Category I (formerly non-designated areas)		Category II		Category III (formerly designated areas)	
	$\mu g/m^3$	ppm*	$\mu g/m^3$	ppm*	$\mu g/m^3$	ppm*
Annual Mean	3	0.001	15	0.005	60	0.021
24-hr max	15	0.005	100	0.035	260**	0.091
3-hr max	75	0.026	700	0.245	1300**	0.455

*Equivalent values in parts per million at 0^o C and 760 mm Hg (Torr)

**Not to be exceeded more than once in a twelve-month period

Source: Colorado Air Pollution Control Commission, 1975

ment projects. Significant studies and reports are reviewed below. These are also pertinent to the general discussion of air quality modeling presented in Section 9 Chapter 6.

Oil Shale-Air Pollution Control (United States Environmental Protection Agency, 1975) - This EPA study evaluates the air pollution potential of oil shale industry development. The analysis is primarily based on the published description of a TOSCO II retorting process as planned for commercial use by the Colony Development Operation. The technology, processes, plans, projections, and environmental impacts of oil shale development are reviewed. The primary emissions anticipated from the process were particulates, SO_2, NO_x and hydrocarbons. The results of dispersion model calculation for concentrations of pollutants near oil shale plants employing TOSCO II and in situ processes are presented. Calculations for the TOSCO II plant assume that best available controls are applied to the process as described by Colony in their environmental impact analysis (Atlantic Richfield Company, 1974). The assumption used in the report is that the oil shale area of Colorado will be subject to a Class II increment under the Federal Significant Deterioration Regulations. Using this assumption, it was concluded that 85% additional control of particulates and 72% additional control of SO_2 are required over that presented in the Atlantic Richfield Company (1974) impact analysis to meet the Class II Standard.

Regional Oil Shale Study - Impact of Oil Shale Industry Upon Air Quality (Marlatt, 1974) - This report, prepared in 1974 for the State of Colorado, presents the results of diffusion modeling of potential sources in the Piceance Basin. "Box" and "Gaussian" models are used. Modeling was done for SO_2, particulates, hydrocarbons, and NO_x. The emission data used was that from the Colony Development Operation Report (Atlantic Richfield Co., 1974). Ground level hydrocarbon concentrations contributed by the plants were found to be negligible. Conclusions on the SO_2 impact are no longer applicable due to a change in Colorado SO_2 regulations (Colorado Air Pollution Control Commission, 1975). The annual average for NO_x was not predicted. No conclusions were made on particulate emission with respect to State regulations.

Air Quality Assessment of the Oil Shale Development Program in the Piceance Creek Basin (Engineering Science, Inc., 1974 - This report, prepared for the U.S. Department of the Interior, analyzes the potential impact of emissions from oil shale processing plants and secondary indirect developments. Short term, long term,and fumigation models were used to evaluate impacts. Modeling for ambient air concentrations was done using data from the Colony Development Corporation Impact Analysis (Atlantic Richfield, 1974. It was concluded in the report that if the EPA Class II Significant Degradation Limits were the "limiting" regulations, oil shale production in the Piceance Creek Basin would be limited to approximately 350,000 bbl/day.

5.4 DATA SUMMARY AND DISCUSSION

The data summaries for February 1975 through January 1976 are presented below. The seasonal breakdown is winter 1975 (February), spring 1975 (March, April, May), summer 1975 (June, July, August), fall 1975 (September, October, November), and winter 1975 -1976 (December, January). Interrelationships between air quality and lower air study meteorological data (these meteorological data are presented in Chapter 6 of this section) were also investigated and are also discussed below.

Gaseous pollutant and suspended particulate concentrations measured at each site are summarized by season and for the year in Tables 3-5-7 through 3-5-12. Minimum, maximum, and arithmetic mean hourly average values for each gaseous pollutant are presented by site. For particulates, the minimum, maximum, and geometric mean of the 24-hr samples are given. A summary of the particulate size distribution data is presented in Table 3-5-13. The results of the seasonal particulate trace element analysis are summarized in Table 3-5-14. Mean concentrations for all parameters were low through the year. The CO, NO, NO_x, SO_2 and H_2S mean concentrations measured were close to the lower limit of detectability for each parameter. Occassional high concentrations were

Table 3-5-7

SEASONAL SUMMARY OF AIR QUALITY PARAMETERS
FOR WINTER 1975 (FEBRUARY), RBOSP

Parameter	Units	Minimum *	Maximum *	Arithmetic Mean
		Site 1		
O_3	ppm	0.021	0.058	0.033
CO	ppm	0.302	2.309	0.638
NO	ppm	0.001	0.184	0.005
NO_x	ppm	0.001	0.189	0.007
CH_4	ppm	0.797	1.448	1.335
THC	ppm	1.055	1.678	1.426
H_2S	ppm	0.000	0.012	0.002
SO_2	ppm	0.001	0.005	0.004
Particulates	$\mu g/m^3$	NA	NA	NA
		Site 2		
CH_4	ppm	1.078	1.557	1.376
THC	ppm	1.140	2.049	1.515
H_2S	ppm	0.001	0.012	0.004
SO_2	ppm	0.001	0.005	0.003
Particulates	$\mu g/m^3$	0.43†	10.06†	2.74**
		Site 3		
O_3	ppm	0.007	0.058	0.027
CO	ppm	0.000	4.212	0.882
NO	ppm	0.000	0.036	0.009
NO_x	ppm	0.001	0.037	0.008
CH_4	ppm	1.036	1.524	1.387
THC	ppm	1.230	1.891	1.517
H_2S	ppm	0.001	0.007	0.003
SO_2	ppm	0.001	0.008	0.001
Particulates	$\mu g/m^3$	2.82†	12.32†	5.34*
		Site 4		
CH_4	ppm	0.988	1.401	1.311
THC	ppm	1.016	1.521	1.369
H_2S	ppm	0.001	0.003	0.015
SO_2	ppm	0.000	0.003	0.002
Particulates	$\mu g/m^3$	0.67†	8.89†	2.54*

*Hourly Average
**Geometric Mean
† Calculated from 24-hr batch sample
NA Not available

Table 3-5-8

SEASONAL SUMMARY OF AIR QUALITY PARAMETERS
FOR SPRING 1975 (MARCH, APRIL, MAY), RBOSP

Parameter	Units	Minimum*	Maximum*	Arithmetic Mean
		Site 1		
O_3	ppm	0.021	0.054	0.037
CO	ppm	0.000	1.291	0.332
NO	ppm	0.000	0.014	0.003
NO_x	ppm	0.000	0.038	0.005
CH_4	ppm	0.864	1.526	1.184
THC	ppm	0.907	1.745	1.272
H_2S	ppm	0.000	0.005	0.001
SO_2	ppm	0.000	0.009	0.003
Particulates	$\mu g/m^3$	7.67†	95.28†	29.31**
		Site 2		
CH_4	ppm	0.875	1.567	1.239
THC	ppm	1.012	1.627	1.389
H_2S	ppm	0.000	0.012	0.002
SO_2	ppm	0.000	0.009	0.002
Particulates	$\mu g/m^3$	0.61†	84.18†	11.40**
		Site 3		
O_3	ppm	0.002	0.069	0.033
CO	ppm	0.000	1.844	0.303
NO	ppm	0.000	0.159	0.005
NO_x	ppm	0.000	0.154	0.008
CH_4	ppm	0.883	1.860	1.291
THC	ppm	0.975	2.678	1.396
H_2S	ppm	0.000	0.008	0.003
SO_2	ppm	0.000	0.012	0.001
Particulates	$\mu g/m^3$	3.49†	163.09†	23.09**
		Site 4		
CH_4	ppm	0.979	1.545	1.213
THC	ppm	1.134	1.678	1.301
H_2S	ppm	0.001	0.008	0.003
SO_2	ppm	0.001	0.022	0.005
Particulates	$\mu g/m^3$	2.70†	111.16†	19.46**

*Hourly average
**Geometric Mean
† Calculated from 24-hr batch sample

Table 3-5-9

SEASONAL SUMMARY OF AIR QUALITY PARAMETERS
FOR SUMMER 1975 (JUNE, JULY, AUGUST), RBOSP

Parameter	Units	Minimum *	Maximum *	Arithmetic Mean
		Site 1		
O_3	ppm	0.000	0.068	0.037
CO	ppm	0.004	3.241	1.102
NO	ppm	0.000	0.039	0.004
NO_x	ppm	0.000	0.032	0.005
CH_4	ppm	0.879	1.196	1.048
THC	ppm	0.971	1.301	1.142
H_2S	ppm	0.000	0.002	0.002
SO_2	ppm	0.001	0.057	0.003
Particulates	$\mu g/m^3$	3.92†	211.47†	21.74 **
		Site 2		
CH_4	ppm	0.045	1.000	0.918
THC	ppm	0.934	1.296	1.115
H_2S	ppm	0.000	0.002	0.000††
SO_2	ppm	0.000	0.011	0.001
Particulates	$\mu g/m^3$	0.92†	95.40†	14.94 **
		Site 3		
O_3	ppm	0.003	0.089	0.032
CO	ppm	0.033	2.532	0.505
NO	ppm	0.000	0.034	0.005
NO_x	ppm	0.000	0.056	0.006
CH_4	ppm	0.811	1.330	1.055
THC	ppm	0.900	1.818	1.147
H_2S	ppm	0.000	0.007	0.001
SO_2	ppm	0.000	0.023	0.001
Particulates	$\mu g/m^3$	13.12†	247.03†	46.88 **
		Site 4		
CH_4	ppm	0.549	1.200	1.003
THC	ppm	0.741	1.359	1.134
H_2S	ppm	0.001	0.016	0.004
SO_2	ppm	0.002	0.031	0.008
Particulates	$\mu g/m^3$	5.58†	140.83†	35.53 **

* Hourly average
** Geometric Mean
† Calculated from 24-hr batch sample
†† Less than significant figures used

Table 3-5-10

SEASONAL SUMMARY OF AIR QUALITY PARAMETERS
FOR FALL 1975 (SEPTEMBER, OCTOBER, NOVEMBER), RBOSP

Parameter	Units	Minimum *	Maximum *	Arithmetic Mean
		Site 1		
O_3	ppm	0.013	0.048	0.025
CO	ppm	0.005	1.963	0.632
NO	ppm	0.000	0.047	0.001
NO_x	ppm	0.000	0.076	0.002
CH_4	ppm	0.095	1.123	0.951
THC	ppm	0.870	1.358	1.043
H_2S	ppm	0.000	0.027	0.001
SO_2	ppm	0.002	0.027	0.003
Particulates	$\mu g/m^3$	<0.06† ††	51.99†	6.21 **
		Site 2		
CH_4	ppm	0.166	1.180	0.975
THC	ppm	0.188	1.362	1.058
H_2S	ppm	0.000	0.011	0.002
SO_2	ppm	0.001	0.014	0.002
Particulates	$\mu g/m^3$	2.13†	101.66†	15.84 **
		Site 3		
O_3	ppm	0.004	0.054	0.027
CO	ppm	0.072	4.584	0.943
NO	ppm	0.000	0.012	0.001
NO_x	ppm	0.000	0.013	0.001
CH_4	ppm	0.781	1.290	1.050
THC	ppm	0.895	1.409	1.105
H_2S	ppm	0.000	0.012	0.002
SO_2	ppm	0.000	0.013	0.003
Particulates	$\mu g/m^3$	5.95†	136.60†	18.36 **
		Site 4		
CH_4	ppm	0.356	1.204	0.997
THC	ppm	0.523	1.238	1.033
H_2S	ppm	0.001	0.029	0.004
SO_2	ppm	0.002	0.046	0.006
Particulates	$\mu g/m^3$	0.31†	469.28†	12.08 **

* Hourly average
**Geometric mean
† Calculated from 24-hr batch sample
†† LDL of particulate measurement technique

Table 3-5-11

SEASONAL SUMMARY OF AIR QUALITY PARAMETERS
FOR WINTER 1975-1976 (DECEMBER, JANUARY), RBOSP

Parameter	Units	Minimum *	Maximum*	Arithmetic Mean
		Site 1		
O_3	ppm	0.014	0.041	0.031
CO	ppm	0.002	0.766	0.301
NO	ppm	0.000	0.009	0.006
NO_x	ppm	0.000	0.010	0.004
CH_4	ppm	0.579	1.180	0.927
THC	ppm	0.889	1.474	1.094
H_2S	ppm	0.001	0.009	0.001
SO_2	ppm	0.001	0.017	0.002
Particulates	$\mu g/m^3$	< 0.06† ††	9.61 †	1.87 **
		Site 2		
CH_4	ppm	0.795	1.315	1.091
THC	ppm	1.024	1.821	1.215
H_2S	ppm	0.001	0.034	0.004
SO_2	ppm	0.000	0.041	0.005
Particulates	$\mu g/m^3$	0.06 †	10.72 †	1.97 **
		Site 3		
O_3	ppm	0.010	0.043	0.027
CO	ppm	0.270	2.656	0.917
NO	ppm	0.000	0.009	0.005
NO_x	ppm	0.000	0.009	0.005
CH_4	ppm	0.988	1.238	1.105
THC	ppm	1.053	1.500	1.200
H_2S	ppm	0.000	0.009	0.003
SO_2	ppm	0.000	0.005	0.001
Particulates	$\mu g/m^3$	0.74 †	13.54 †	4.34 **
		Site 4		
CH_4	ppm	0.775	1.463	1.073
THC	ppm	0.811	1.802	1.119
H_2S	ppm	0.001	0.065	0.014
SO_2	ppm	0.002	0.060	0.015
Particulates	$\mu g/m^3$	0.25 †	12.13 †	2.95 **

* Hourly average
** Geometric Mean
† Calculated from 24-hr batch sample
†† LDL of particulates measurement technique

Table 3-5-12

ANNUAL SUMMARY OF AIR QUALITY PARAMETERS
(FEBRUARY 1975 THROUGH JANUARY 1976), RBOSP

Parameter	Units	Minimum**	Maximum**	Arithmetic Mean
		Site 1		
O_3	ppm	0.000	0.068	0.033
CO	ppm	0.000	3.241	0.618
NO	ppm	0.000	0.047	0.003
NO_x	ppm	0.000	0.076	0.004
CH_4	ppm	0.095	1.526	1.059
THC	ppm	0.837	1.745	1.163
H_2S	ppm	0.000	0.027	0.001
SO_2	ppm	0.000	0.057	0.003
Particulates	$\mu g/m^3$	< 0.06† ††	211.47†	9.07*
		Site 2		
CH_4	ppm	0.045	1.567	1.075
THC	ppm	0.188	1.821	1.198
H_2S	ppm	0.000	0.034	0.002
SO_2	ppm	0.000	0.041	0.002
Particulates	$\mu g/m^3$	0.06†	101.66†	9.20*
		Site 3		
O_3	ppm	0.000	0.089	0.030
CO	ppm	0.000	4.584	0.645
NO	ppm	0.000	0.159	0.004
NO_x	ppm	0.000	0.154	0.005
CH_4	ppm	0.781	1.860	1.147
THC	ppm	0.895	2.768	1.233
H_2S	ppm	0.000	0.012	0.002
SO_2	ppm	0.000	0.023	0.001
Particulates	$\mu g/m^3$	0.74†	247.03†	18.00*
		Site 4		
CH_4	ppm	0.356	1.545	1.087
THC	ppm	0.523	1.802	1.165
H_2S	ppm	0.001	0.065	0.005
SO_2	ppm	0.000	0.060	0.007
Particulates	$\mu g/m^3$	0.25†	469.28†	12.61*

* Geometric Mean
** Hourly Average
† Calculated from 24-hr batch sample
†† LDL of particulate measurement technique

Table 3-5-13

SUMMARY OF SIZE DISTRIBUTION
OF PARTICULATES AT SITE 1, RBOSP

DATE	PARTICULATE CONCENTRATION BY PARTICLE SIZE RANGE **				
	7.2-00 microns	3.0-7.2 microns	1.5-3.0 microns	0.95-1.5 microns	0-0.95 microns
28 April	<0.06	<0.06	<0.06	<0.06	7.67
10 May	<0.06	<0.06	<0.06	<0.06	10.85
22 May	0.31	1.04	<0.06	1.04	6.56
3 June	<0.06	<0.06	<0.06	<0.06	6.25
15 June	<0.06	<0.06	<0.06	<0.06	9.93
27 June	<0.06	<0.06	<0.06	<0.06	24.22
9 July	0.68	<0.06	<0.06	<0.06	12.63
21 July	<0.06	<0.06	0.92	<0.06	17.54
2 August	<0.06	1.00	0.55	<0.06	13.24
17 August	1.16	<0.06	<0.06	<0.06	6.44
26 August	<0.06	<0.06	<0.06	<0.06	5.95
4 September	0.31	0.31	<0.06	<0.06	10.18
28 September	0.61	0.18	<0.06	<0.06	10.42
10 October	0.31	0.06	0.31	<0.06	11.83
22 October	0.42	0.79	0.55	0.61	7.66
28 October	<0.06	<0.06	<0.06	0.18	0.12
3 November	<0.06	<0.06	<0.06	<0.06	<0.06
15 November	<0.06	<0.06	<0.06	<0.06	0.31
27 November	<0.06	0.61	0.98	0.73	12.13
9 December	1.28	1.47	1.53	1.41	3.92
21 December	<0.06	<0.06	<0.06	<0.06	0.43
2 Janruary	<0.06	<0.06	<0.06	<0.06	2.57
14 Janruary	<0.06	<0.06	<0.06	<0.06	0.73
26 Janruary	<0.06	<0.06	<0.06	<0.06	1.72

* "Equivalent Aerodynamic Diameter" is defined as the size of a spherical particle of density 1 gm/cc which has the same terminal setting velocity as the sampled particle.

** Sierra Instruments, Inc., 1975

Table 3-5-14
HIGH VOLUME FILTER ANALYTICAL TRACE ELEMENT RESULTS, RBOSP

PARAMETER	CONCENTRATION (ng/cm^2)			
	SPRING	SUMMER	FALL	WINTER**
Uranium	<0.01	Internal Standard	<0.18	0.11
Thorium	<0.01	<0.01	0.56	0.25
Bismuth	<0.01	<0.01	0.49	0.12
Lead	45	19	12	9.5
Thallium	<0.01	<0.01	<0.47	<0.01
Mercury	NR*	0.1	0.2	0.3
Gold	<0.01	<0.01	<0.10	<0.01
Platinum	<0.01	<0.01	<0.10	<0.01
Iridium	<0.01	<0.01	<0.10	<0.01
Osmium	<0.01	<0.01	<0.10	<0.01
Rhenium	Internal Standard	Internal Standard	Internal Standard	Internal Standard
Tungsten	<0.01	<0.01	<0.36	<0.01
Tantalum	<0.01	<0.01	2.3	<0.01
Hafnium	<0.01	<0.01	<0.10	<0.01
Lutecium	<0.01	<0.01	<0.10	<0.01
Ytterbium	<0.01	<0.01	<0.10	<0.01
Thullium	<0.01	<0.01	<0.10	<0.01
Erbium	<0.01	<0.01	<0.10	<0.01
Holmium	<0.01	<0.01	<0.10	<0.01
Oysprosium	<0.01	NR*	<0.10	<0.01
Terbium	<0.01	<0.01	<0.10	<0.01
Gadolinium	<0.01	<0.01	<0.10	<0.01
Europium	<0.01	<0.01	<0.10	<0.01
Samarium	<0.01	0.01	<0.10	<0.01
Neodymium	<0.01	0.01	0.28	<0.01
Praseodymium	<0.01	0.23	0.73	<0.01
Cerium	3.5	11	3.1	0.39
Lanthanum	1.6	2.8	0.78	0.54
Barium	21	56	34	6.4
Cesium	<0.01	0.16	<0.10	<0.01
Iodine	<0.01	<0.01	0.26	<0.01
Tellurium	<0.01	<0.01	<0.10	<0.01
Antimony	<0.01	0.25	0.14	0.27
Tin	0.96	5.1	0.66	0.86
Indium	Internal Standard	Internal Standard	Internal Standard	Internal Standard
Cadmium	<0.01	<0.01	<0.10	<0.01
Silver	<0.01	<0.01	0.47	<0.01
Palladium	<0.01	<0.01	<0.10	<0.01
Rhodium	<0.01	<0.01	0.10	<0.01
Ruthenium	<0.01	<0.01	0.10	NR*
Molybdenum	19	13	<2.0	0.73
Niobium	0.50	1.4	1.1	0.45
Zirconium	2.2	5.6	5.8	0.96
Yttrium	0.91	2.1	0.63	0.18
Strontium	12	12	38	3.5
Rubidium	4.2	9.5	5.6	0.57
Bromine	1.8	1.6	0.30	0.79
Selenium	<0.01	0.37	1.5	0.21
Arsenic	1	0.62	4.0	2.4
Germanium	<0.01	<0.01	<0.10	<0.01
Gallium	<0.01	1.7	1.8	<0.01
Zinc	<0.01	36	11	58
Copper	76	470	170	170
Nickel	<0.01	<75	7.7	5.8
Cobalt	NR*	<7	0.84	0.22
Iron	NR*	~1400	3400	NR*
Manganese	NR*	<38	91	6.7
Chromium	NR*	<28	21	6.7
Vanadium	5.3	6.4	11	5.8
Titanium	380	510	650	42
Scandium	<0.01	0.42	0.42	<0.01
Calcium	~1700	~3500	10000	770
Potassium	~2200	~1240	6000	450
Chlorine	43	67	4.8	31
Sulphur	530	<520	660	160
Phosphorus	82	170	800	130
Silicon	≈4800	75000	82000	NR*
Aluminum	670	~2100	14000	NR*
Magnesium	960	~1500	4200	230
Sodium	High Blank	<740	2000	290
Fluorine	420	62	340	71
Oxygen	NR*	NR*	NR*	NR*
Nitrogen	NR*	NR*	NR*	NR*
Carbon	NR*	NR*	NR*	NR*
Boron	0.01	NR*	NR*	NR*
Beryllium	0.01	<0.01	0.19	<0.01
Lithium	5.0	37	2.7	1.0

NR* = Not Reported

**December,1975 - January, 1976

measured for particulates in the spring, summer, and fall; for non-methane hydrocarbons in the summer, fall, and winter (1975-1976); and for ozone in the summer. The highest concentration measured for each of these three parameters during the year were for particulates 469 $\mu g/m^3$ in October; for ozone 0.089 ppm (177 $\mu g/m^3$) in August; and for non-methane hydrocarbons 0.594 ppm (394 $\mu g/m^3$) in June.

Measurements of particulate size distribution (Table 3-5-13) show that the majority of particles collected have an equivalent aerodynamic diameter of less than 0.95 microns. The highest total particulate concentration measured during particle sizing was greater than 24.22 $\mu g/m^3$. The data do not indicate that the distribution of particle size changes with the total mass of particulates collected.

Quarterly trace element analyses (Tables 3-5-14) were performed to document particulate composition before Tract C-a development.

A. Comparison of Air Quality Data with Federal and State Standards - Gaseous and particulate concentrations measured at each site were compared with the applicable Federal and State ambient air standards. A summary of the comparison results for each quarter and for the year is given in Tables 3-5-15 through 3-5-20. These tables show the standards, the total number of times each standard was exceeded at all sites during the time period covered by the table, and the maximum concentration measured at each site for the averaging time interval specified by each standard.

Table 3-5-15

COMPARISON OF FEDERAL AND STATE AIR QUALITY STANDARDS TO MEASUREMENTS MADE DURING WINTER 1975 (FEBRUARY), RBOSP

PARAMETER	STANDARDS				TIMES STANDARD EXCEEDED DURING QUARTER	MEASURED MAXIMUM Site 1			MEASURED MAXIMUM Site 2			MEASURED MAXIMUM Site 3			MEASURED MAXIMUM Site 4		
	Type of Standard 5/	Time Interval	Concentration µg/m³	Concentration ppm		Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time
CO	Primary and Secondary 1/	1-hr max.	40,000	35	0	2639	2.309	1800 2/21	———	———	———	4894	4.212	1200 2/12	———	———	———
CO	Primary and Secondary 1/	8-hr max.	10,000	9	0	1084	0.933	0800 2/6	———	———	———	4232	3.642	1800 2/12	———	———	———
Non-methane Hydrocarbon	Primary and Secondary 1/	3-hr max. (6-9 am only)	160	0.24	0	108	0.162	2/6	139	0.210	2/3	135	0.204	2/6	65	0.099	2/15
NO_2	Primary and Secondary 1/	Annual Arith. Mean	100	0.05	NA	4 3/	0.002 3/	NA	———	———	———	0 3/	0.000 3/	NA	———	———	———
Ozone	Primary and Secondary 1/	1-hr max.	160	0.08	0	116	0.058	1700 2/2	———	———	———	116	0.058	1900 2/10	———	———	———
SO_2	Primary 1/	24-hr max.	365	0.14	0	13	0.005	2000 2/4	8	0.003	1200 2/11	8	0.003	2000 2/25	19	0.007	1600 2/3
SO_2	Primary 1/	Annual Arith. Mean	80	0.03	NA	11 3/	0.004 3/	NA	8	0.003 3/	NA	3 3/	0.001 3/	NA	5 3/	0.002 3/	NA
SO_2	Secondary 1/	3-hr max.	1300	0.5	0	13	0.005	1500 2/21	19	0.007	1500 2/10	16	0.006	0600 2/24	151	0.057	1800 2/2
Particulates	Primary 1/	24-hr max	260	NA	0	Not Avail.	NA	NA	10	NA	2/19	12	NA	2/19	9	NA	2/19
Particulates	Primary 1/	Annual Geo. Mean	75	NA	NA	Not Avail.	NA	NA	3 4/	NA	NA	5 4/	NA	NA	3 4/	NA	NA
Particulates	Secondary 1/	24-hr max.	150	NA	0	Not Avail.	NA	NA	10	NA	2/19	12	NA	2/19	9	NA	2/19
Particulates	Secondary 1/	Annual Geo. Mean	60	NA	NA	Not Avail.	NA	NA	3 4/	NA	NA	5 4/	NA	NA	3 4/	NA	NA
Particulates	State 2/	24-hr max.	150 6/	NA	0	Not Avail.	NA	NA	8	NA	2/19	9	NA	2/19	7	NA	2/19
Particulates	State 2/	Annual Arith. Mean	45 6/	NA	NA	Not Avail.	NA	NA	3 3/	NA	NA	5 3/	NA	NA	3 3/	NA	NA

1/Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards (40 CFR 50; 36 FR 22384, November 25, 1971: as amended by 38 FR 25678, September 14, 1973; 40 FR 7042, February 18, 1975).
2/Ambient air standards for metropolitan Denver air quality control region, air quality control areas, and the State of Colorado; Adopted: September 10, 1970, Effective: December 17, 1970.
3/Arithmetic mean of values measured during the quarter.
4/Geometric mean of values measured during the quarter.
5/All EPA standards are at reference conditions of 25°C and 760 mm Hg.
6/Measured at ambient temperature and pressure.
NA = Not Applicable.
___ = Not measured at this site.

Table 3-5-16

COMPARISON OF FEDERAL AND STATE AIR QUALITY STANDARDS TO MEASUREMENTS MADE DURING SPRING 1975 (MARCH, APRIL, MAY), RBOSP

PARAMETER	STANDARDS				TIMES STANDARD EXCEEDED DURING QUARTER	MEASURED MAXIMUM Site 1			MEASURED MAXIMUM Site 2			MEASURED MAXIMUM Site 3			MEASURED MAXIMUM Site 4		
	Type of Standard 5/	Time Interval	Concentration µg/m³	Concentration ppm		Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time
CO	Primary and Secondary 1/	1-hr max.	40,000	35	0	1500	1.291	1300 3/27	——	——	——	2143	1.844	1000 3/4	——	——	——
CO	Primary and Secondary 1/	8-hr max.	10,000	9	0	1385	1.192	0300 3/23	——	——	——	1169	1.006	1700 3/4	——	——	——
Non-methane Hydrocarbon	Primary and Secondary 1/	3-hr max. (6-9 am only)	160	0.24	0	141	0.213	3/12	129	0.195	5/21	120	0.181	5/28	110	0.166	5/27
NO_2	Primary and Secondary 1/	Annual Arith. Mean	100	0.05	NA	4 3/	0.002 3/	NA	——	——	——	6 3/	0.003 3/	NA	——	——	——
Ozone	Primary and Secondary 1/	1-hr max.	160	0.08	0	108	0.054	2000 5/21	——	——	——	137	0.069	1400 4/16	——	——	——
SO_2	Primary 1/	24-hr max.	365	0.14	0	21	0.008	0700 5/11	8	0.003	1700 5/28	13	0.005	2100 3/11	55	0.021	2100 5/21
SO_2	Primary 1/	Annual Arith. Mean	80	0.03	NA	8 3/	0.003 3/	NA	5 3/	0.002 3/	NA	3 3/	0.001 3/	NA	13 3/	0.005 3/	NA
SO_2	Secondary 1/	3-hr max.	1300	0.5	0	24	0.009	0700 5/11	18	0.007	0400 5/29	32	0.012	1500 3/20	284	0.107	0300 5/21
Particulates	Primary 1/	24-hr max	260	NA	0	95	NA	5/4	84	NA	5/4	163	NA	4/25	111	NA	4/25
Particulates	Primary 1/	Annual Geo. Mean	75	NA	NA	28 4/	NA	NA	11 4/	NA	NA	24 4/	NA	NA	19 4/	NA	NA
Particulates	Secondary 1/	24-hr max.	150	NA	1	95	NA	5/4	84	NA	5/4	163	NA	4/25	111	NA	4/25
Particulates	Secondary 1/	Annual Geo. Mean	60	NA	NA	28 4/	NA	NA	11 4/	NA	NA	24 4/	NA	NA	19 4/	NA	NA
Particulates	State 2/	24-hr max.	150 6/	NA	0	73	NA	5/4	64	NA	5/4	125	NA	4/25	85	NA	4/25
Particulates	State 2/	Annual Arith. Mean	45 6/	NA	NA	28 3/	NA	NA	14 3/	NA	NA	26 3/	NA	NA	24 3/	NA	NA

1/Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards (40 CFR 50; 36 FR 22384, November 25, 1971: as amended by 38 FR 25678, September 14, 1973; 40 FR 7042, February 18, 1975).
2/Ambient air standards for metropolitan Denver air quality control region, air quality control areas, and the State of Colorado; Adopted: September 10, 1970, Effective: December 17, 1970.
3/Arithmetic mean of values measured during the quarter.
4/Geometric mean of values measured during the quarter.
5/All EPA standards are at reference conditions of 25°C and 760 mm Hg.
6/Measured at ambient temperature and pressure.
NA = Not Applicable.
—— = Not measured at this site.

Table 3-5-17

COMPARISON OF FEDERAL AND STATE AIR QUALITY STANDARDS TO MEASUREMENTS MADE DURING SUMMER 1975 (JUNE, JULY, AUGUST), RBOSP

PARAMETER	STANDARDS				TIMES STANDARD EXCEEDED DURING QUARTER	MEASURED MAXIMUM Site 1			MEASURED MAXIMUM Site 2			MEASURED MAXIMUM Site 3			MEASURED MAXIMUM Site 4		
	Type of Standard 5/	Time Interval	Concentration µg/m³	Concentration ppm		Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time
CO	Primary and Secondary 1/	1-hr max.	40,000	35	0	3766	3.241	0700 7/18	___	___	___	2942	2.532	0100 8/1	___	___	___
CO	Primary and Secondary 1/	8-hr max.	10,000	9	0	3585	3.085	0800 7/18	___	___	___	1404	1.208	2200 8/15	___	___	___
Non-methane Hydrocarbon	Primary and Secondary 1/	3-hr max. (6-9 am only)	160	0.24	20	140	0.211	6/29	286	0.431	8/25	130	0.196	8/7	394	0.594	6/9
NO_2	Primary and Secondary 1/	Annual Arith. Mean	100	0.05	NA	2 3/	0.001 3/	NA	___	___	___	2 3/	0.001 3/	NA	___	___	___
Ozone	Primary and Secondary 1/	1-hr max.	160	0.08	5	135	0.068	1200 7/7	___	___	___	177	0.089	1900 8/29	___	___	___
SO_2	Primary 1/	24-hr max.	365	0.14	0	37	0.014	1700 7/31	3	0.001	2200 7/17	13	0.005	0400 7/31	48	0.018	2100 7/16
SO_2	Primary 1/	Annual Arith. Mean	80	0.03	NA	8 3/	0.003 3/	NA	3 3/	0.001 3/	NA	3 3/	0.001 3/	NA	21 3/	0.008 3/	NA
SO_2	Secondary 1/	3-hr max.	1300	0.5	0	114	0.043	1600 7/31	8	0.003	0100 7/17	50	0.019	0700 7/30	159	0.060	2100 7/16
Particulates	Primary 1/	24-hr max	260	NA	0	212	NA	7/3	95	NA	6/24	247	NA	8/17	141	NA	6/24
Particulates	Primary 1/	Annual Geo. Mean	75	NA	NA	21 4/	NA	NA	15 4/	NA	NA	47 4/	NA	NA	36 4/	NA	NA
Particulates	Secondary 1/	24-hr max.	150	NA	3	212	NA	7/3	95	NA	6/24	247	NA	8/17	141	NA	6/24
Particulates	Secondary 1/	Annual Geo. Mean	60	NA	NA	21 4/	NA	NA	15 4/	NA	NA	47 4/	NA	NA	36 4/	NA	NA
Particulates	State 2/	24-hr max.	150 6/	NA	3	162	NA	7/3	73	NA	6/24	189	NA	8/17	108	NA	6/24
Particulates	State 2/	Annual Arith. Mean	45 6/	NA	NA	28 3/	NA	NA	21 3/	NA	NA	45 3/	NA	NA	36 3/	NA	NA

1/Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards (40 CFR 50; 36 FR 22384, November 25, 1971: as amended by 38 FR 25678, September 14, 1973; 40 FR 7042, February 18, 1975).
2/Ambient air standards for metropolitan Denver air quality control region, air quality control areas, and the State of Colorado; Adopted: September 10, 1970, Effective: December 17, 1970.
3/Arithmetic mean of values measured during the quarter.
4/Geometric mean of values measured during the quarter.
5/All EPA standards are at reference conditions of 25°C and 760 mm Hg.
6/Measured at ambient temperature and pressure.
NA = Not Applicable.
___ = Not measured at this site.

Table 3-5-18

COMPARISON OF FEDERAL AND STATE AIR QUALITY STANDARDS TO MEASUREMENTS MADE DURING FALL 1975 (SEPTEMBER, OCTOBER, NOVEMBER), RBOSP

PARAMETER	STANDARDS				TIMES STANDARD EXCEEDED DURING QUARTER	MEASURED MAXIMUM Site 1			MEASURED MAXIMUM Site 2			MEASURED MAXIMUM Site 3			MEASURED MAXIMUM Site 4		
	Type of Standard 5/	Time Interval	Concentration $\mu g/m^3$	Concentration ppm		Concentration $\mu g/m^3$	Concentration ppm	Time	Concentration $\mu g/m^3$	Concentration ppm	Time	Concentration $\mu g/m^3$	Concentration ppm	Time	Concentration $\mu g/m^3$	Concentration ppm	Time
CO	Primary and Secondary 1/	1-hr max.	40,000	35	0	2281	1.963	1000 10/23	___	___	___	5326	4.584	1100 9/1	___	___	___
CO	Primary and Secondary 1/	8-hr max.	10,000	9	0	1263	1.087	1600 10/23	___	___	___	4418	3.802	1100 9/1	___	___	___
Non-methane Hydrocarbon	Primary and Secondary 1/	3-hr max. (6-9 am only)	160	0.24	11	303	0.456	9/20	289	0.436	9/2	78	0.117	9/23	92	0.139	9/30
NO_2	Primary and Secondary 1/	Annual Arith. Mean	100	0.05	NA	2 3/	0.001 3/	NA	___	___	___	0 3/	0.000 3/	NA	___	___	___
Ozone	Primary and Secondary 1/	1-hr max.	160	0.08	0	96	0.048	2300 9/2	___	___	___	108	0.054	1900 9/18	___	___	___
SO_2	Primary 1/	24-hr max.	365	0.14	0	11	0.004	2100 9/5	24	0.009	1700 10/17	19	0.007	1300 11/1	82	0.031	1800 10/23
SO_2	Primary 1/	Annual Arith. Mean	80	0.03	NA	8 3/	0.003 3/	NA	5 3/	0.002 3/	NA	8 3/	0.003 3/	NA	16 3/	0.006 3/	NA
SO_2	Secondary 1/	3-hr max.	1300	0.5	0	32	0.012	2200 11/27	178	0.067	2000 10/16	24	0.009	10/31	345	0.130	2200 10/22
Particulates	Primary 1/	24-hr max	260	NA	1	52	NA	9/19	102	NA	10/7	137	NA	10/7	469	NA	10/7
Particulates	Primary 1/	Annual Geo. Mean	75	NA	NA	6 4/	NA	NA	16 4/	NA	NA	18 4/	NA	NA	12 4/	NA	NA
Particulates	Secondary 1/	24-hr max.	150	NA	1	52	NA	9/19	102	NA	10/7	137	NA	10/7	469	NA	10/7
Particulates	Secondary 1/	Annual Geo. Mean	60	NA	NA	6 4/	NA	NA	16 4/	NA	NA	18 4/	NA	NA	12 4/	NA	NA
Particulates	State 2/	24-hr max.	150 6/	NA	1	40	NA	9/19	78	NA	10/7	105	NA	10/7	360	NA	10/7
Particulates	State 2/	Annual Arith. Mean	45 6/	NA	NA	9 3/	NA	NA	17 3/	NA	NA	20 3/	NA	NA	25 3/	NA	NA

1/Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards (40 CFR 50; 36 FR 22384, November 25, 1971: as amended by 38 FR 25678, September 14, 1973; 40 FR 7042, February 18, 1975).
2/Ambient air standards for metropolitan Denver air quality control region, air quality control areas, and the State of Colorado; Adopted: September 10, 1970, Effective: December 17, 1970.
3/Arithmetic mean of values measured during the quarter.
4/Geometric mean of values measured during the quarter.
5/All EPA standards are at reference conditions of 25°C and 760 mm Hg.
6/Measured at ambient temperature and pressure.
NA = Not Applicable.
___ = Not measured at this site.

Table 3-5-19

COMPARISON OF FEDERAL AND STATE AIR QUALITY STANDARDS TO MEASUREMENTS MADE DURING WINTER 1975-1976 (DECEMBER, JANUARY), RBOSP

PARAMETER	STANDARDS				TIMES STANDARD EXCEEDED DURING QUARTER	MEASURED MAXIMUM Site 1			MEASURED MAXIMUM Site 2			MEASURED MAXIMUM Site 3			MEASURED MAXIMUM Site 4		
	Type of Standard 5/	Time Interval	Concentration µg/m³	Concentration ppm		Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time
CO	Primary and Secondary 1/	1-hr max.	40,000	35	0	890	0.766	0000 12/6	___	___	___	3086	2.656	1700 12/30	___	___	___
CO	Primary and Secondary 1/	8-hr max.	10,000	9	0	840	0.723	0400 12/6	___	___	___	2060	1.773	0000 12/31	___	___	___
Non-methane Hydrocarbon	Primary and Secondary 1/	3-hr max. (6-9 am only)	160	0.24	21	212	0.320	12/23	154	0.232	12/1	122	0.184	2300 1/24	154	0.232	1/24
NO_2	Primary and Secondary 1/	Annual Arith. Mean	100	0.05	NA	0	0.000 3/	NA	___	___	___	0	0.000 3/	NA	___	___	___
Ozone	Primary and Secondary 1/	1-hr max.	160	0.08	0	82	0.041	1900 1/24	___	___	___	86	0.043	1500 12/6	___	___	___
SO_2	Primary 1/	24-hr max.	365	0.14	0	8	0.003	0600 12/6	11	0.0004	1800 12/31	8	0.003	1700 12/5	11	0.004	1500 12/14
SO_2	Primary 1/	Annual Arith. Mean	80	0.03	NA	5 3/	0.002 3/	NA	13/	0.005 3/	NA	3 3/	0.001 3/	NA	40 3/	0.015 3/	NA
SO_2	Secondary 1/	3-hr max.	1300	0.5	0	21	0.008	1900 12/4	8	0.003	2100 12/30	8	0.003	1900 1/27	45	0.017	1800 12/13
Particulates	Primary 1/	24-hr max	260	NA	0	10	NA	12/9	11	NA	12/12	14	NA	12/12	12	NA	12/12
Particulates	Primary 1/	Annual Geo. Mean	75	NA	NA	2 4/	NA	NA	2 4/	NA	NA	4 4/	NA	NA	3 4/	NA	NA
Particulates	Secondary 1/	24-hr max.	150	NA	0	10	NA	12/9	11	NA	12/12	14	NA	12/12	12	NA	12/12
Particulates	Secondary 1/	Annual Geo. Mean	60	NA	NA	2 4/	NA	NA	2 4/	NA	NA	4 4/	NA	NA	3 4/	NA	NA
ticulates	State 2/	24-hr max.	150 6/	NA	0	7	NA	12/9	8	NA	12/12	10	NA	12/12	9	NA	12/12
Particulates	State 2/	Annual Arith. Mean	45 6/	NA	NA	2 3/	NA	NA	2 3/	NA	NA	4 3/	NA	NA	3 3/	NA	NA

1/Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards (40 CFR 50; 36 FR 22384, November 25, 1971: as amended by 38 FR 25678, September 14, 1973; 40 FR 7042, February 18, 1975).
2/Ambient air standards for metropolitan Denver air quality control region, air quality control areas, and the State of Colorado; Adopted: September 10, 1970, Effective: December 17, 1970.
3/Arithmetic mean of values measured during the quarter.
4/Geometric mean of values measured during the quarter.
5/All EPA standards are at reference conditions of 25°C and 760 mm Hg.
6/Measured at ambient temperature and pressure.
NA = Not Applicable.
___ = Not measured at this site.

Table 3-5-20

COMPARISON OF FEDERAL AND STATE AIR QUALITY STANDARDS TO MEASUREMENTS MADE FOR THE YEAR (FEBRUARY 1975 THROUGH JANUARY 1976), RBOSP

PARAMETER	STANDARDS				TIMES STANDARD EXCEEDED DURING YEAR	MEASURED MAXIMUM Site 1			MEASURED MAXIMUM Site 2			MEASURED MAXIMUM Site 3			MEASURED MAXIMUM Site 4		
	Type of Standard 5/	Time Interval	Concentration µg/m³	Concentration ppm		Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time	Concentration µg/m³	Concentration ppm	Time
CO	Primary and Secondary 1/	1-hr max.	40,000	35	0	3766	3.241	0700 7/18	____	____	____	5326	4.584	1100 9/1	____	____	____
CO	Primary and Secondary 1/	8-hr max.	10,000	9	0	3585	3.085	0800 7/18	____	____	____	4418	3.802	1100 9/1	____	____	____
Non-methane Hydrocarbon	Primary and Secondary 1/	3-hr max. (6-9 am only)	160	0.24	60	303	0.456	9/20	289	0.436	9/2	135	0.204	2/6	394	0.594	6/9
NO_2	Primary and Secondary 1/	Annual Arith. Mean	100	0.05	0	2	0.001	2/1/75-1/31/76	____	____	____	2	0.001	2/1/75-1/31/76	____	____	____
Ozone	Primary and Secondary 1/	1-hr max.	160	0.08	5	135	0.068	1200 7/4	____	____	____	177	0.089	1900 8/29	____	____	____
SO_2	Primary 1/	24-hr max.	365	0.14	0	37	0.014	1700 7/31	24	0.009	1700 10/17	19	0.007	1300 11/1	82	0.031	1800 10/28
SO_2	Primary 1/	Annual Arith. Mean	80	0.03	0	8	0.003	2/1/75-1/31/76	5	0.002	2/1/75-1/31/76	3	0.001	2/1/75 1/31/76	19	0.007	2/1/75-1/31/76
SO_2	Secondary 1/	3-hr max.	1300	0.5	0	114	0.043	1600 7/31	178	0.067	2000 10/16	50	0.019	0700 7/30	345	0.130	2200 10/22
Particulates	Primary 1/	24-hr max	260	NA	1	212	NA	7/3	102	NA	10/7	247	NA	8/17	469	NA	10/7
Particulates	Primary 1/	Annual Geo. Mean	75	NA	0	9	NA	2/1/75-1/31/76	9	NA	2/1/75-1/31/76	18	NA	2/1/75-1/31/76	13	NA	2/1/75-1/31/76
Particulates	Secondary 1/	24-hr max.	150	NA	5	212	NA	7/3	102	NA	10/7	247	NA	8/17	469	NA	10/7
Particulates	Secondary 1/	Annual Geo. Mean	60	NA	0	9	NA	2/1/75-1/31/76	9	NA	2/1/75-1/31/76	18	NA	2/1/75-1/31/76	13	NA	2/1/75-1/31/76
Particulates	State 2/	24-hr max.	150 6/	NA	4	162	NA	7/3	78	NA	10/7	189	NA	8/17	360	NA	10/7
Particulates	State 2/	Annual Arith. Mean	45 6/	NA	0	16	NA	2/1/75-1/31/76	14	NA	2/1/75-1/31/76	24	NA	2/1/75-1/31/76	22	NA	2/1/75-1/31/76

1/Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards (40 CFR 50; 36 FR 22384, November 25, 1971: as amended by 38 FR 25678, September 14, 1973; 40 FR 7042, February 18, 1975).
2/Ambient air standards for metropolitan Denver air quality control region, air quality control areas, and the State of Colorado; Adopted: September 10, 1970, Effective: Oecember 17, 1970.
3/Arithmetic mean of values measured during the quarter.
4/Geometric mean of values measured during the quarter.
5/All EPA standards are at reference conditions of 25°C and 760 mm Hg.
6/Measured at ambient temperature and pressure.
NA = Not Applicable.
____ = Not measured at this site.

Mean concentrations measured for all parameters were low compared to the standards (Tables 3-5-12 and 3-5-19). Particulates, ozone, and non-methane hydrocarbons occassionally exceeded the standards, however. Federal 24-hr maximum primary particulate standards were exceeded once during the year, in the fall, and Federal 24-hr maximum secondary particulate standards were exceeded five times during the year, once during the spring, three times during the summer, and once in the fall. The Federal primary and secondary annual standard (geometric mean) was not exceeded for the study year. The range of annual geometric means for particulates was 9 to 18$\mu g/m^3$, which is 12 to 24% of the Federal primary annual standard and 15 to 30% of the Federal secondary annual standard. State 24-hr particulate standards were exceeded four times during the year, three times in the summer and once in the fall. State annual standard (arithmetic mean) was not exceeded for the study year. The range of annual arithmetic means for the year was 14 to 24 $\mu g/m^3$ which is 31 to 53% of the State Standard. Federal primary and secondary 1-hr maximum ozone standards were exceeded five times during the year, all occurrences being in the summer. Non-methane hydrocarbon concentrations exceeded Federal primary and secondary 3-hr maximum (6-9 am only) standards 60 times during the year, 28 times during the summer, 11 times during the fall, and 21 times during the winter (1975-1976). There are no known local sources of hydrocarbons to account for the existence of these high concentrations of non-methane hydrocarbons.

In addition to the standards shown in Tables 3-5-15 through 3-5-20, there is a State of Colorado SO_2 ambient air standard (Colorado Air Pollution Control Commission, 1975). This SO_2 standard became effective in December 1975. It established maximum allowable increases in ambient SO_2 concentrations over existing background levels. The background levels are to be determined by measurement or estimation. The present baseline monitoring program will, therefore, help define the background level of the area. The background

levels of SO_2 measured on Tract C-a are shown in Table 3-5-21.

Table 3-5-21

SO_2 BACKGROUND CONCENTRATIONS FOR ALL SITES
FOR TRACT C-a, RBOSP

Time Interval	Concentration	
	$\mu g/m^3$	ppm
Annual Mean	11	0.004
24-hr Maximum	82	0.031
3-hr Maximum	345	0.130

B. Air Quality and Meteorological Interrelationships - The rate of dilution and direct dispersion of substances released into the atmosphere are determined by meteorological conditions. In addition, some of the substances which are agency regulated are naturally occurring and their formation is governed to an extent by local atmospheric conditions. To investigate some of the possible interrelationships, correlation comparison plots between air quality parameters and other air quality and meteorological parameters were computer generated from the baseline data taken on Tract C-a (Section 3 Chapter 6). Correlation checks were performed among the following parameters:

- Sulfur Dioxide
- Hydrocarbons
- Ozone
- Total Oxides of Nitrogen
- Particulates
- Wind Direction
- Wind Speed
- Relative Humidity
- Insolation
- Wind Sigma
- Delta Temperature

Data points were plotted in the form of scatter diagrams which graphically present information of both the correlation and the frequency of occurrence of each set of values.

A scatter diagram plots a point for each simultaneous occurrence of ordinate and abscissa value. More than one point can occur for each position in the scatter plot, i.e., there can be more than one occurrence of a set of values. Using the rank of alphabetic characters ("A" equal to one to "Z" equal to twenty-six) to correspond to the number of occurrences of a particular set of values, information was incorporated on the number of occurrences of each set of values making up the scatter plot. Values in excess of 26 occurrences are represented by an asterisk (*). In addition, the point representing the arithmetic mean value of the ordinate was calculated for each abscissa point and denoted by a line. Using these lines, a trace was drawn on the plot. This plotting of the average ordinate value for the abscissa points produces a graphic presentation of the correlation and the trend. The correlations considered significant are discussed below.

1. Sulfur Dioxide and Hydrogen Sulfide - Plots of sulfur dioxide and hydrogen sulfide with wind speed, wind direction, insolation and delta temperature (vertical thermal gradient) showed no significant correlations. In each case, changes in the air quality parameter could not be identified with changes in the meteorological parameter. This result can be attributed to the extremely low values of these compounds which are routinely measured on the tract and the fact that no significant sources of sulfur are known in the area. The plots of sulfur dioxide versus several meteorological variables shown in Figure 3-5-3 are typical of the scatter diagram plots showing no significant interrelationships.

The lower detectable threshold (or LDL) of the SO_2/H_2S monitoring instrument is 0.005 ppm. The average curves of SO_2 all lie beneath this lower detection threshold for all ranges of the meteorological parameters considered. The alternately blank rows in these plots are the result of the data transmission technique. The minimum signal increment produced by the digital data

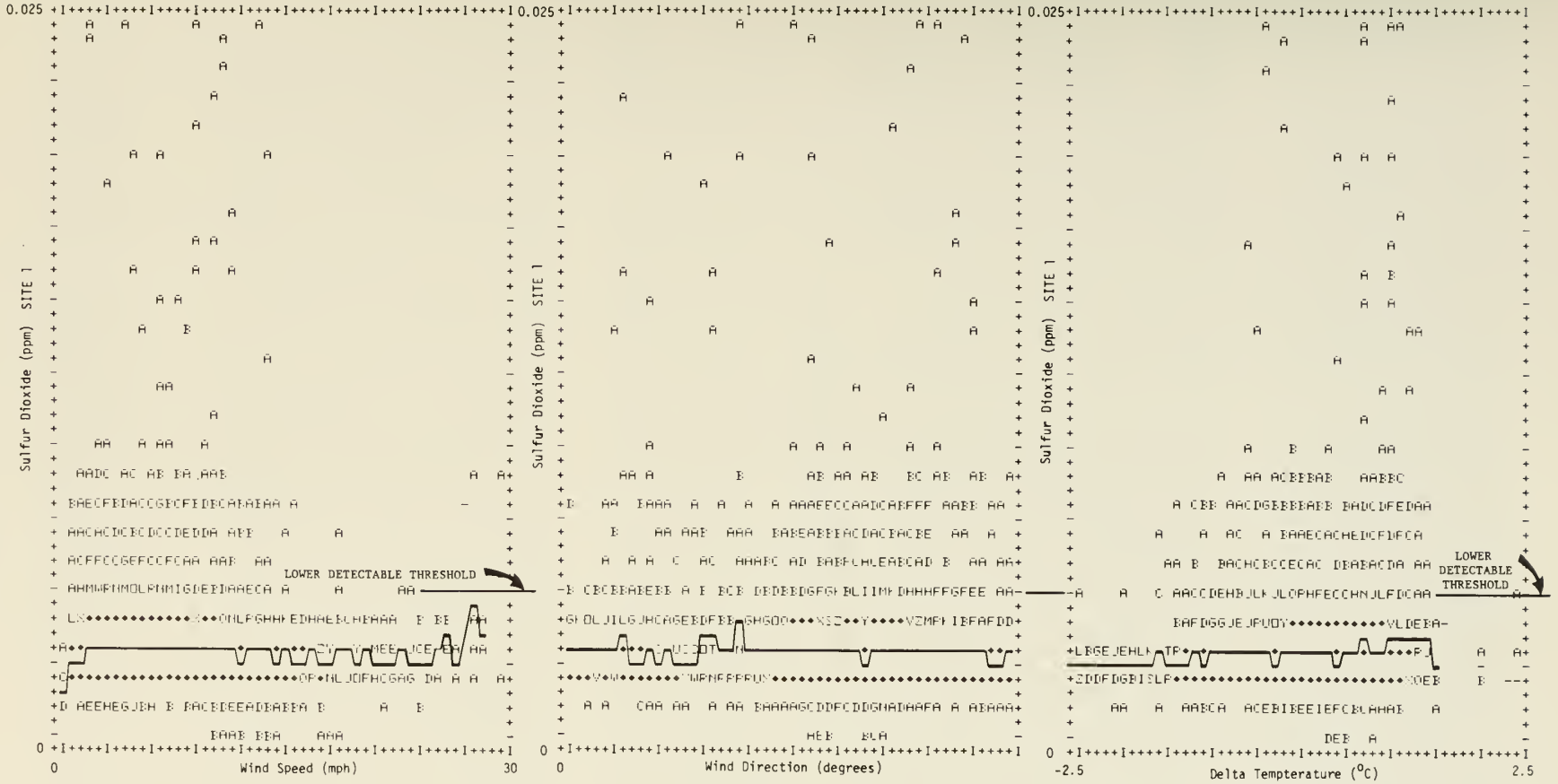


Figure 3-5-3
CORRELATION OF SULFUR DIOXIDE CONCENTRATIONS WITH WIND SPEED, WIND DIRECTION, AND DELTA TEMPERATURE, SITE 1, RBOSP

acquisition system used to record the data corresponds to 0.001 ppm signal of sulfur dioxide concentration. For a full scale range on the correlation plots of 0.025 ppm this necessitates that only even multiples of the smallest increment shown on the diagrams have values assigned. The small variations in the average curves are not meaningful. They are due to the quantization of the data imposed by these types of plots.

2. Hydrocarbons - In contrast to the sulfur dioxide and hydrogen sulfide concentrations, hydrocarbon concentrations measured during the baseline monitoring year were at levels well above the detection limit of the monitoring instruments. The source of these compounds is believed to be local vegetation (Halligan, 1975; Muller, Muller and Haines, 1964; Geissman and Irwin, 1974). Although relatively constant through the daylight hours, both total hydrocarbons (THC) and methane (CH_4) exhibited a definite diurnal variation. Plots of the THC and methane concentrations versus hour of the day for all four monitoring locations are presented in Figure 3-5-4. The diurnal effect was greatest at Site 3. Of the four monitoring sites, Site 3 has the greatest amount of vegetative ground cover around it. Site 4 ranks second in ground cover with both of these sites situated within valleys. For a more complete description of the site topography and its relation to the dispersive capacity of the atmosphere near the tract, see Section 3 Chapter 6.

The relationship between total hydrocarbon concentration and wind direction showed no preferred directions of higher concentration at Sites 1 and 2 and only a minimal interrelationship between the two at Sites 3 and 4. However, the behavior of total hydrocarbon concentration in relation to wind speed is straightforward for all four sites. As wind speed increases, there is a slight trend towards lower concentrations as shown in Figure 3-5-5. This can be attributed to the greater mixing which occurs during the high wind speed conditions diluting the boundary layer gases with air from the upper atmosphere.

3. Nitrogen Oxides - Interrelationships between ozone and nitrogen oxides were investigated because photochemical correlation between these compounds is

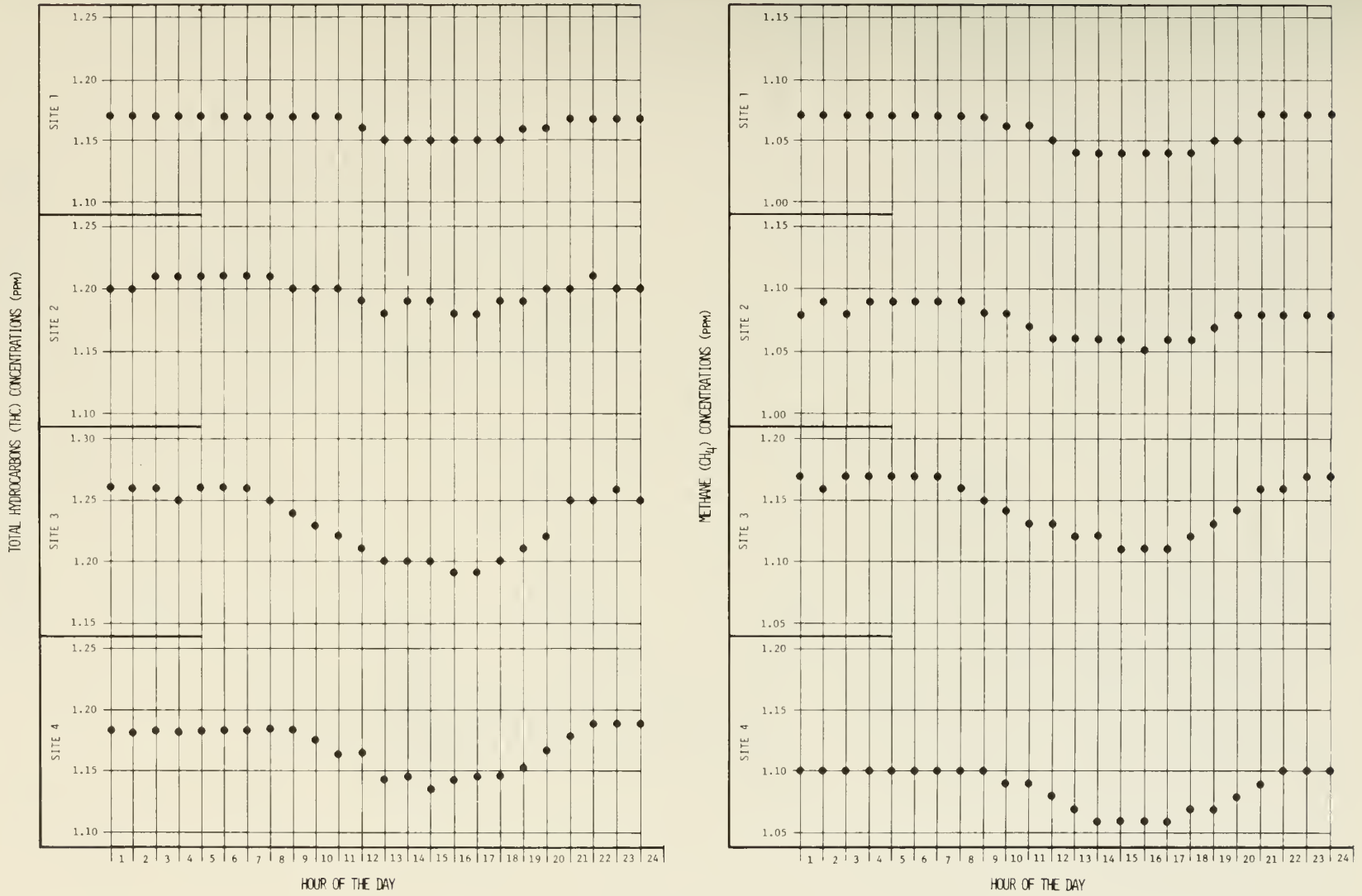


Figure 3-5-4

DIURNAL VARIATION OF METHANE AND TOTAL HYDROCARBONS AT SITES 1, 2, 3 AND 4, RBOSP

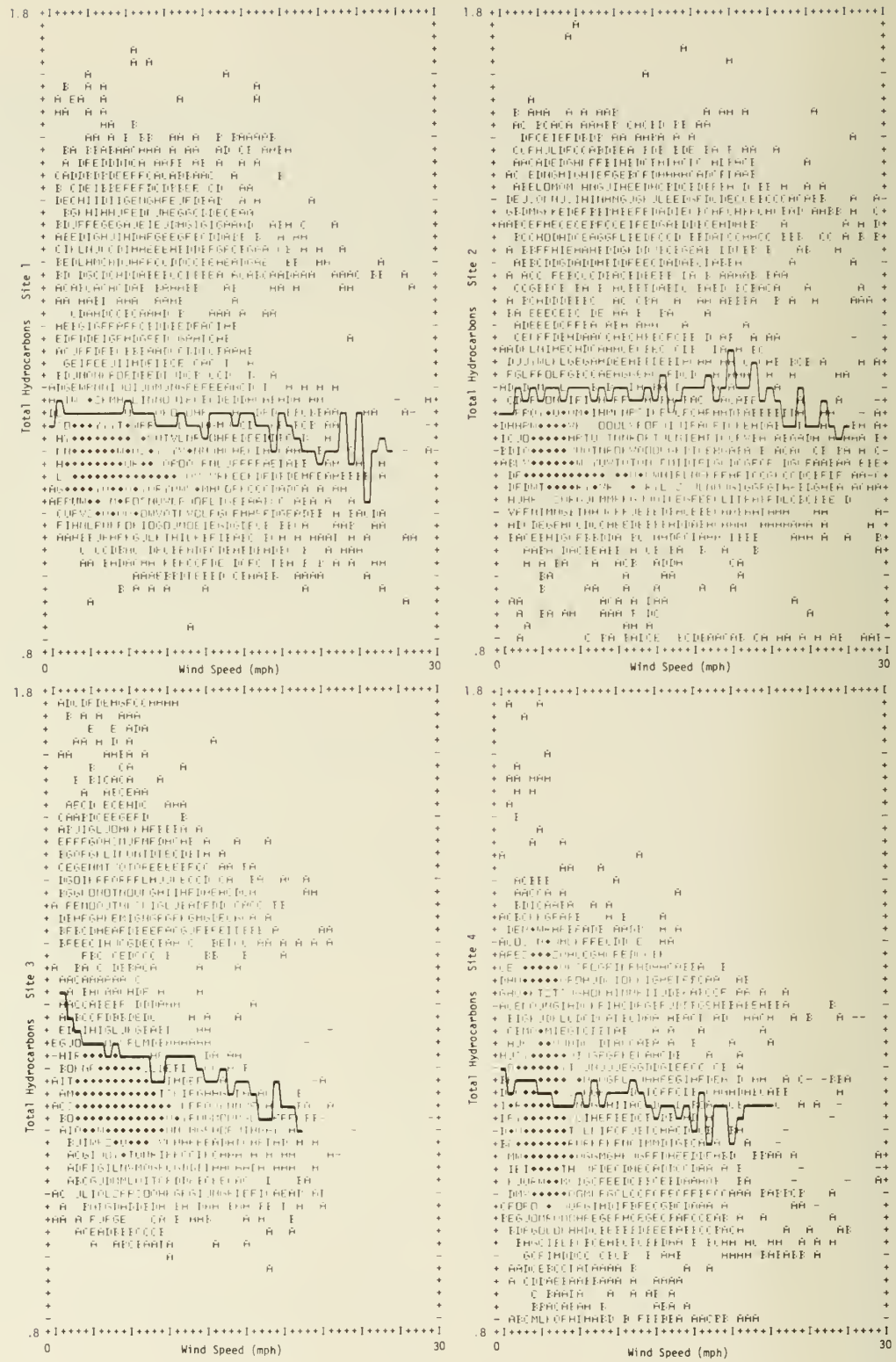


Figure 3-5-5

CORRELATION OF TOTAL HYDROCARBONS AND WIND SPEED, SITES 1, 2, 3 AND 4, RBOSP

Total Hydrocarbons (ppm)

known to exist. The lack of an observable correlation between O_3 and NO_x may be because the levels of NO_x (≃5ppb) are low compared to the ozone levels (≃33ppb). In addition, this mean NO_x concentration is approximately equal to the numerical accuracy of the ozone measurement technique. Therefore, reactions of nitrogen oxides with the ozone may not reduce the ozone concentration enough to be differentiated from the natural variability of the ozone value. The behavior of NO_x with ozone at both Sites 1 and 3 is shown in Figure 3-5-6.

4. Ozone - The correlations between ozone concentration and meteorological variables (Section 3 Chapter 6) are presented in Figures 3-5-7 through 3-5-9. Correlation between ozone and wind direction showed no significant interrelationship. As can be seen from diagrams A and B in Figure 3-5-7, there is a sharp rise in ozone values for positive delta temperature (ΔT) conditions. As can be seen from the other diagrams (C and D) in Figure 3-5-7, a similar effect is responsible for increase in ozone concentration with increasing solar insolation. The mechanism for ozone production appears to be solar radiation (photochemical reaction). The fact that the delta temperature (stability discussion Section 3 Chapter 6) is also dependent upon incoming radiation is an example of a parametric effect. The small but rapid rise in O_3 for extremely stable thermal conditions (ΔT less than -2.0^{o} C) can probably be attributed to persistent trapping episodes (phenomena is only observed within the valley at Site 3) with little or no dilution near the surface. This effect is not as large as the solar insolation-caused high concentrations produced during the day under unstable thermal conditions, however.

The associations between measured ozone concentrations and wind speed and relative humidity, shown in Figure 3-5-8, also show a parametic effect. Data show (Figure 3-6-26) that relative humidity decreases with increased wind speed. Data also show that wind speeds during the daylight hours are typically higher than during the nighttime hours (Figure 3-6-10) and ozone concentrations are higher for larger wind speeds. In addition, the relative humidity is at a minimum during the afternoon hours (Figure 3-6-25) and consequently ozone concentration shows an increase with decreasing humidity.

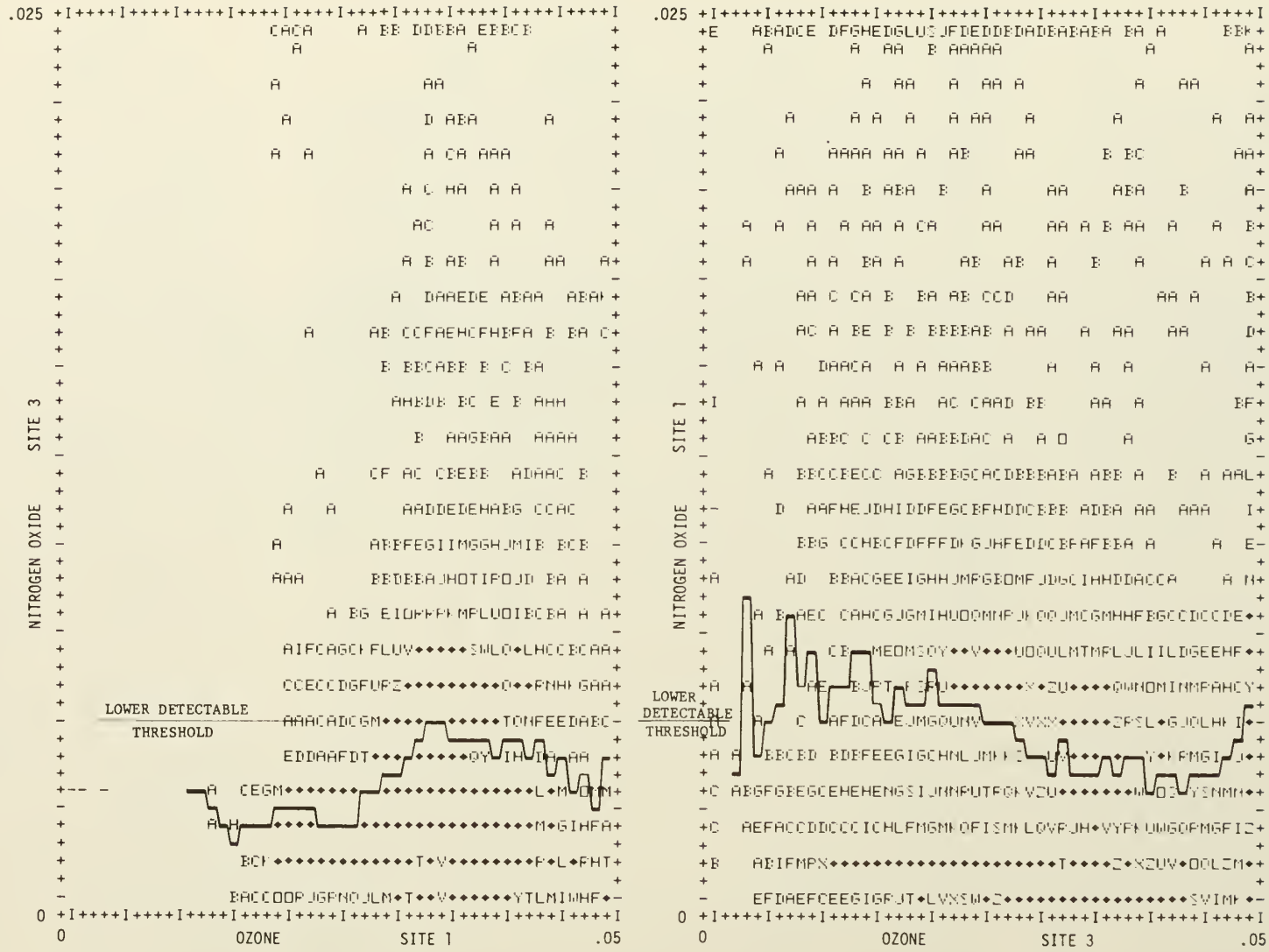


Figure 3-5-6

CORRELATION OF TOTAL OXIDES OF NITROGEN
WITH OZONE, SITES 1 AND 3, RBOSP
Nitrogen Oxide and Ozone (ppm)

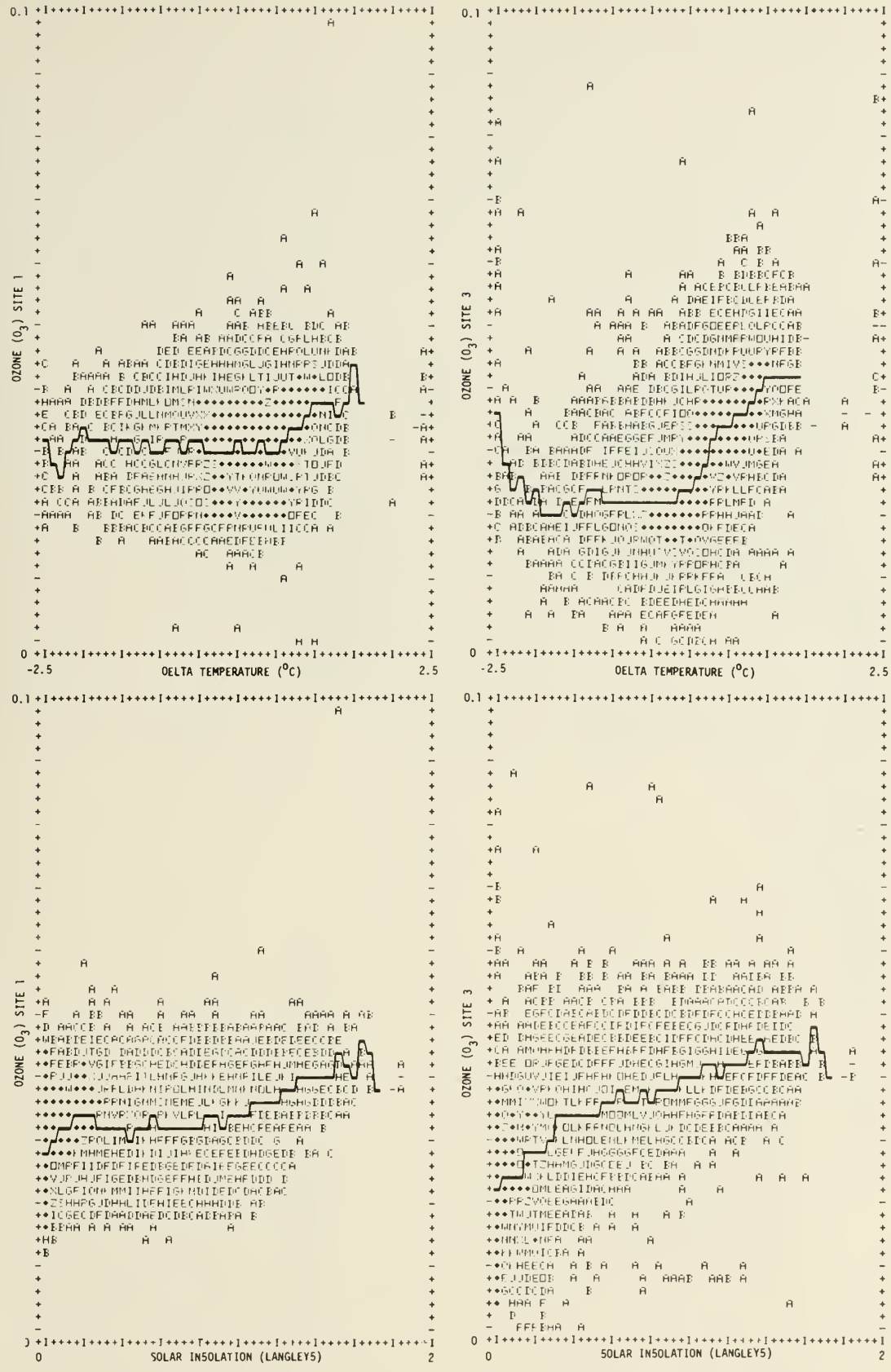


Figure 3-5-7

CORRELATION OF OZONE (PPM) WITH DELTA TEMPERATURE AND SOLAR INSOLATION, SITES 1 AND 3, RBOSP

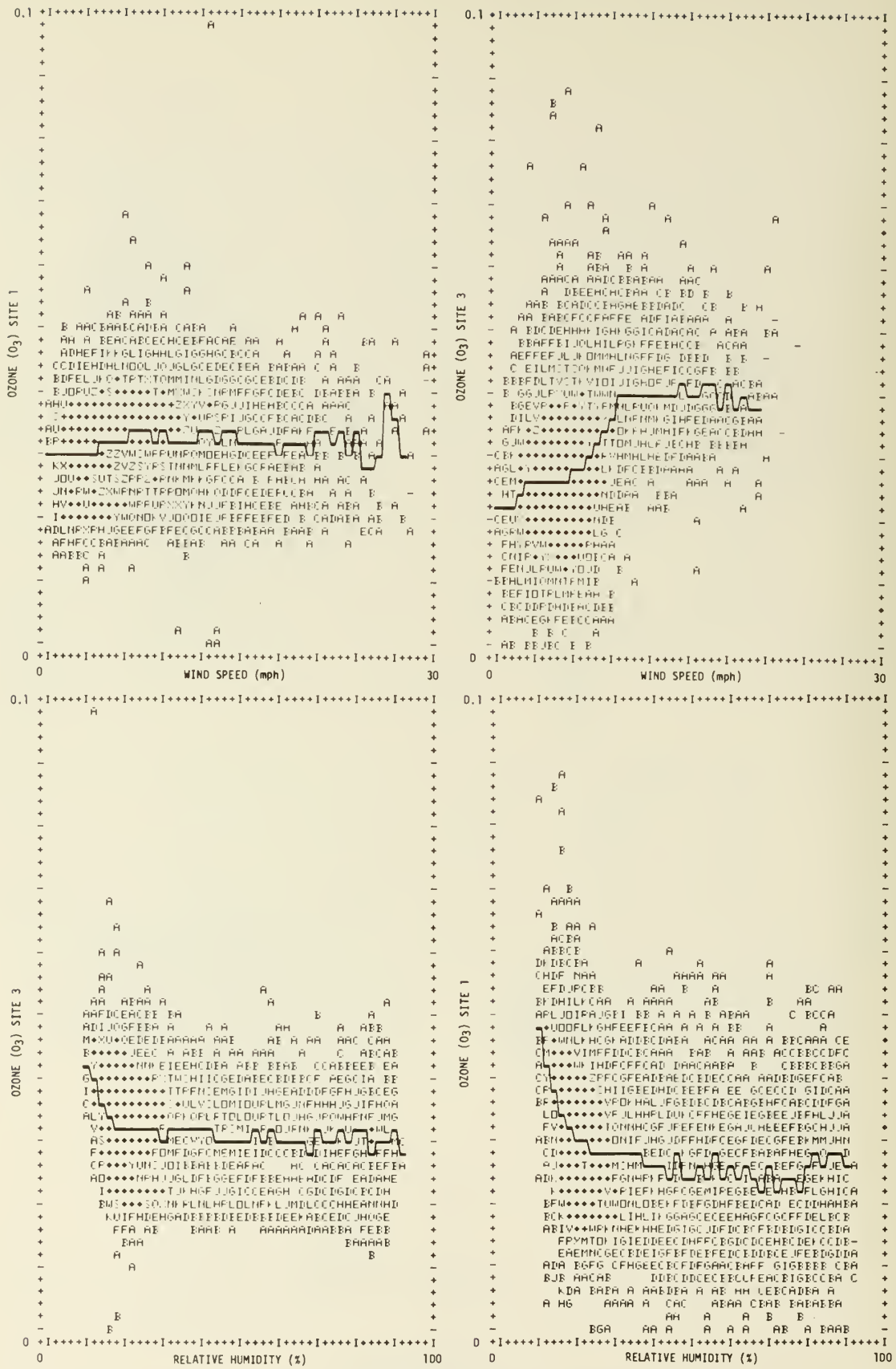
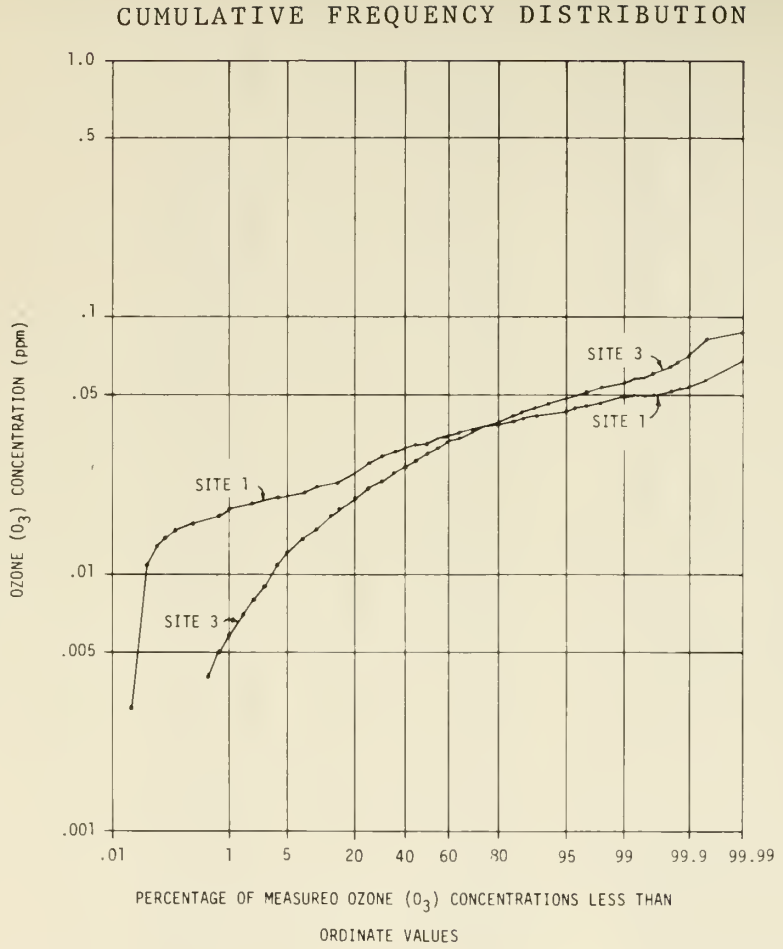


Figure 3-5-8
CORRELATION OF OZONE (PPM) WITH WIND SPEED AND RELATIVE HUMIDITY, SITES 1 AND 3, RBOSP



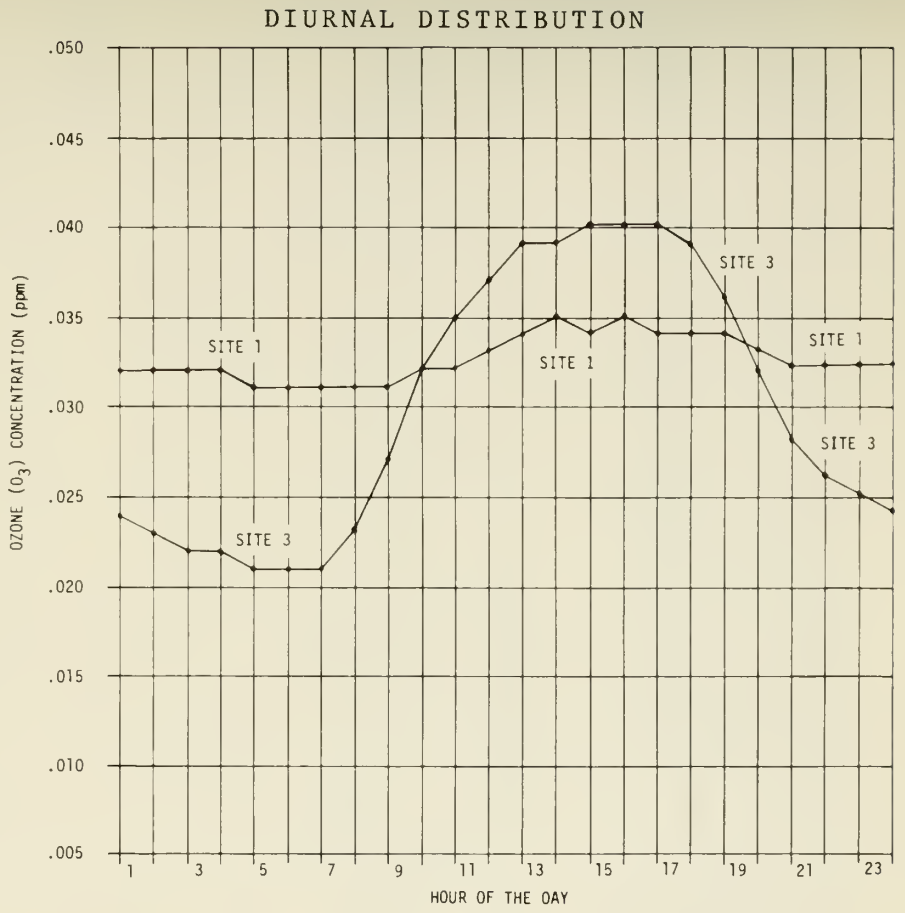


Figure 3-5-9

DISTRIBUTION OF OZONE CONCENTRATIONS
MEASURED AT SITES 1 AND 3, RBOSP

The actual diurnal distribution of the hourly average values of ozone concentrations at Sites 1 and 3, along with their cumulative frequency distribution by concentration magnitude, are shown in Figure 3-5-9. The relative magnitude of the diurnal variation at Site 3 is larger than that at Site 1, however the time intervals at both sites over which changes took place correspond closely.

Cumulative frequency and diurnal distributions of ozone concentrations at each of these two sites are shown in Figure 3-5-9. It can be seen from the cumulative frequency distribution that a significant number of hourly observations approach the 1-hr ambient standard of 0.08 ppm. Even with the difference between the two curves, the median values at the two sites are comparable (0.030 versus 0.033 ppm, respectively). Because the concentrations of ozone have a definite diurnal variation (non-stochastic), they cannot be expected to follow a log-normal distribution. (See particulates discussion below for an explanation of log-normal distributions).

5. Particulates - Because of the general concern over the total particulate loading of the atmosphere in the vicinity of the tract, the behavior of particulate concentrations was analyzed extensively to investigate the possible relationship between particulate concentrations and other meteorological variables. To address this behavior, stochastic processes must be understood.

If a variable (e.g., particulate concentration) is dependent upon its past values in addition to a new (possible random) source, it can be expressed as:

$$X_i = X_{i-1} + X_{i-1} Y_i$$

where X_i is the most recent measurement of the variable, X_{i-1} is the old value and Y_i is an independent variable (e.g., related to winds, humidity, or frontal system passage). Then:

$$Y_i = \frac{X_i - X_{i-1}}{X_{i-1}} \quad .$$

Summation over a number of observations gives:

$$\Sigma Y_i = \sum \frac{X_i - X_{i-1}}{X_{i-1}} \quad .$$

The right hand side of this expression can be converted to a function solvable by integration by assuming it is a continuous process. This results in:

$$\Sigma Y_i = \int \frac{dX}{X}$$

and thus:

$$\ln X \simeq \Sigma Y_i \quad .$$

Because Y is an independent random variable (or a number of different independent random variables), for a large number of observations ΣY_i is a normally distributed variable and X is log-normally distributed.

Plots of the cumulative frequency distribution on log-normal probability paper by concentration of the particulates at each of the four monitoring sites are presented in Figure 3-5-10. The data fit the log-normal curve well, although they are not perfect fits to log-normal distributions. The arithmetic and geometric means of the baseline data sets are shown on each plot for comparison with the median value. Using the assumption that these data are representative, the baseline data distribution predicts ambient air standards will be exceeded during a typical year (Federal Secondary Standard is 150 $\mu g/m^3$).

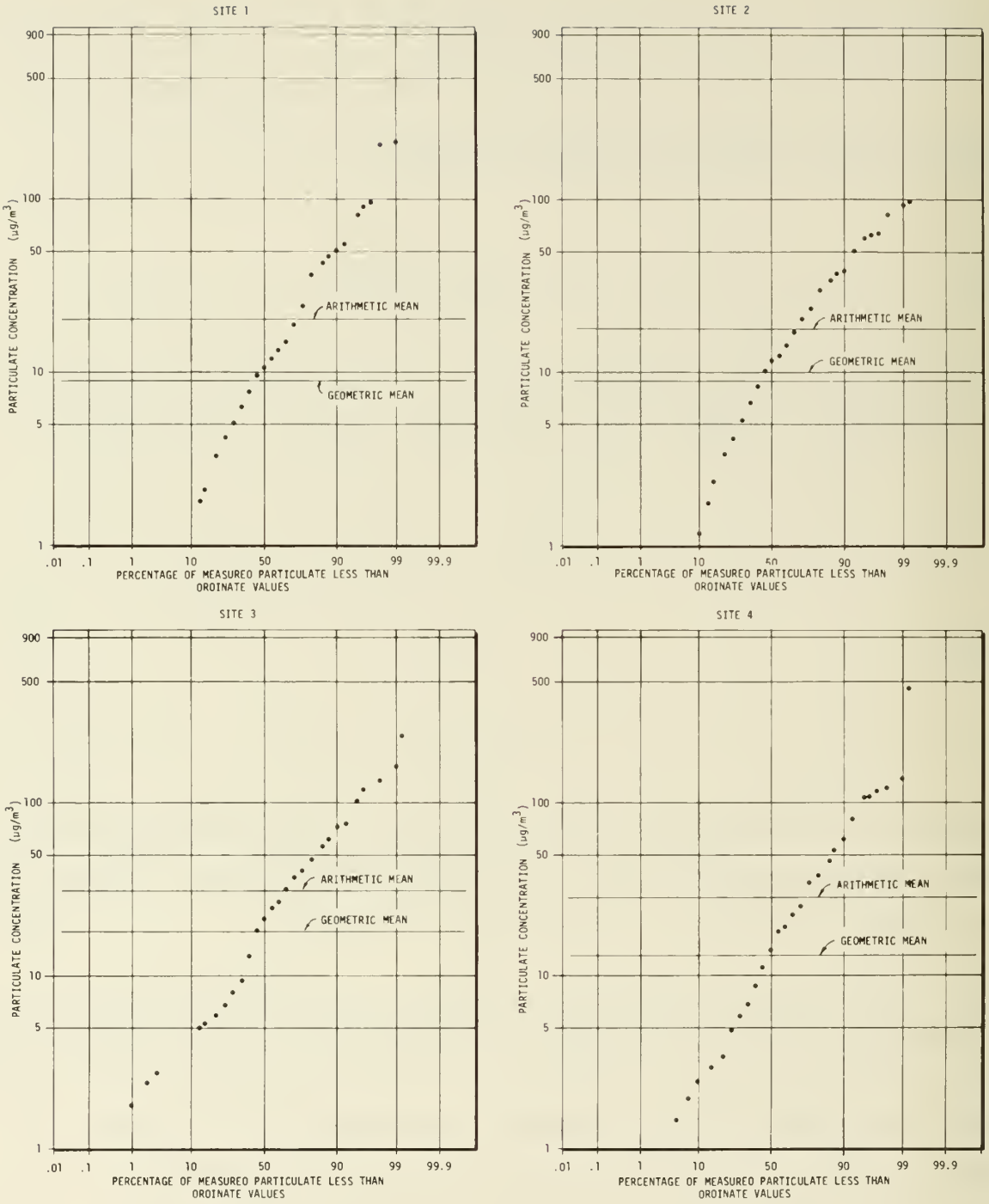


Figure 3-5-10

CUMULATIVE FREQUENCY DISTRIBUTION OF
PARTICULATES FOR SITES 1, 2, 3 AND 4, RBOSP

To investigate the correlation between the particulate concentrations at the four sites, scatter diagrams were plotted (Figure 3-5-11). The particulate concentrations between sites agree well, Sites 3 and 4 having the greatest correlation (valley site versus valley site).

Although there is scatter between wind speed (24-hr mean) and particulate concentration as measured at each of the four sites, the general trend is for higher wind speeds to be associated with higher particulate loading. Correlation plots showing this are presented in Figure 3-5-12. These plots present the 24-hr average particulate concentration versus the daily averaged wind speeds for the same day at each site. Plots of maximum wind speed versus particulate concentrations for each site were also made. Although not presented herein, these indicate the same scatter pattern.

In contrast to the increase in particulate loading with higher wind speeds, increased relative humidity should tend to lower the particulate concentration. This is expected because higher humidity can be related to precipitation events and, therefore, higher ambient air scavanging potential. In addition, high humidity is related to cohesion between surface particles, cohesion increasing with increased moisture content. Scatter diagrams plotting daily averaged relative humidity at Site 1 versus particulate concentration at each of the four monitoring sites shows this general behavior (Figure 3-5-13). However, relative humidity before the advance of a frontal system is normally low, while the wind speeds are generally high and gusty. In addition, high gusts normally occur before the onslaught of thunderstorm activity while the relative humidity remains low. Indeed, thunderstorms in this region of the country often produce extensive air motion with little if any precipitation. Thus, the correlation between relative humidity and particulate concentration is not as great as that between wind speed and particulate loading.

A presentation of the detailed meteorological conditions associated with the 5 days of highest concentration measured at each of the four sites is presented in Section 9 Chapter 5.

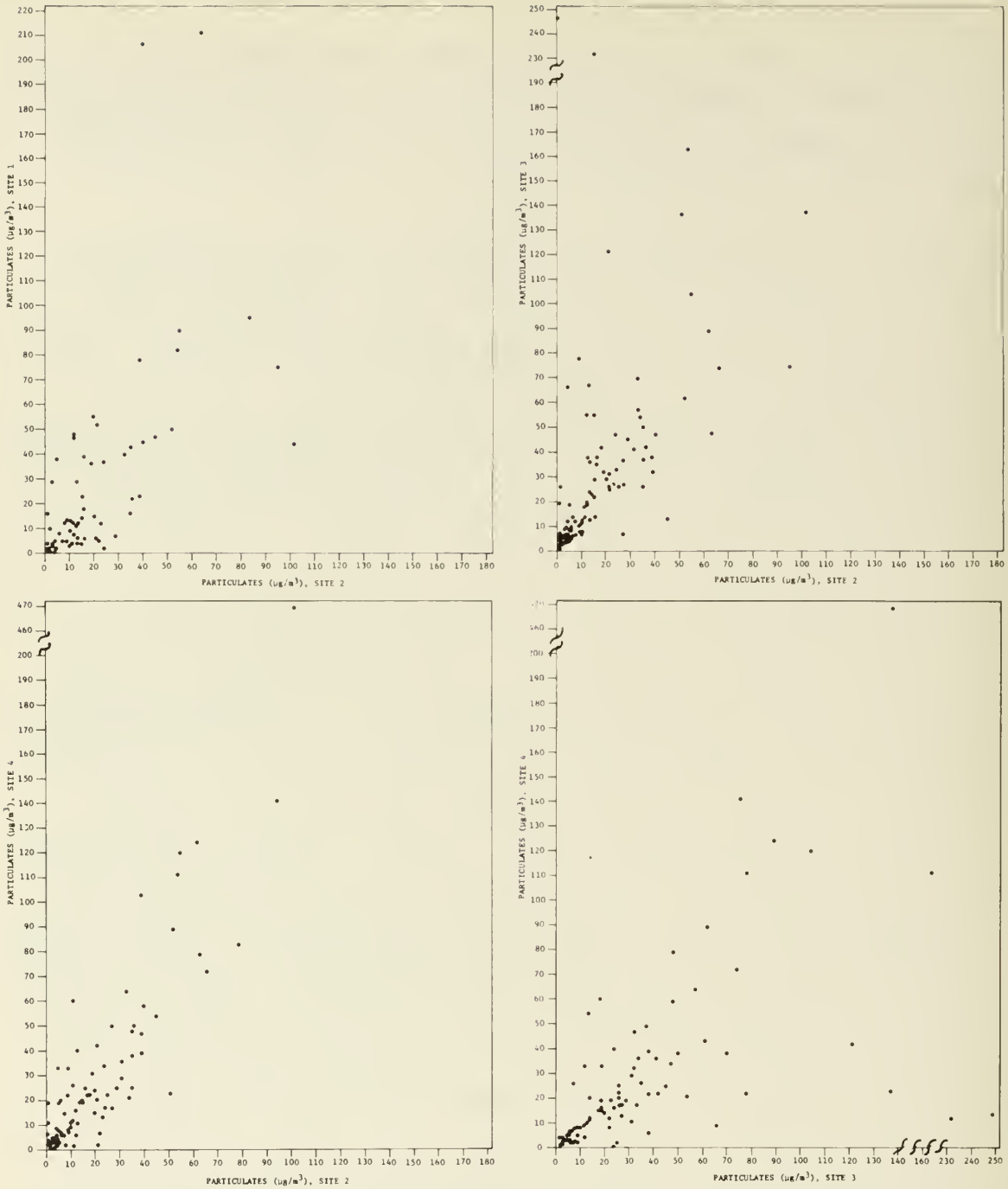


Figure 3-5-11

CORRELATION BETWEEN PARTICULATE CONCENTRATIONS
AT SITES 1, 2, 3 AND 4, RBOSP

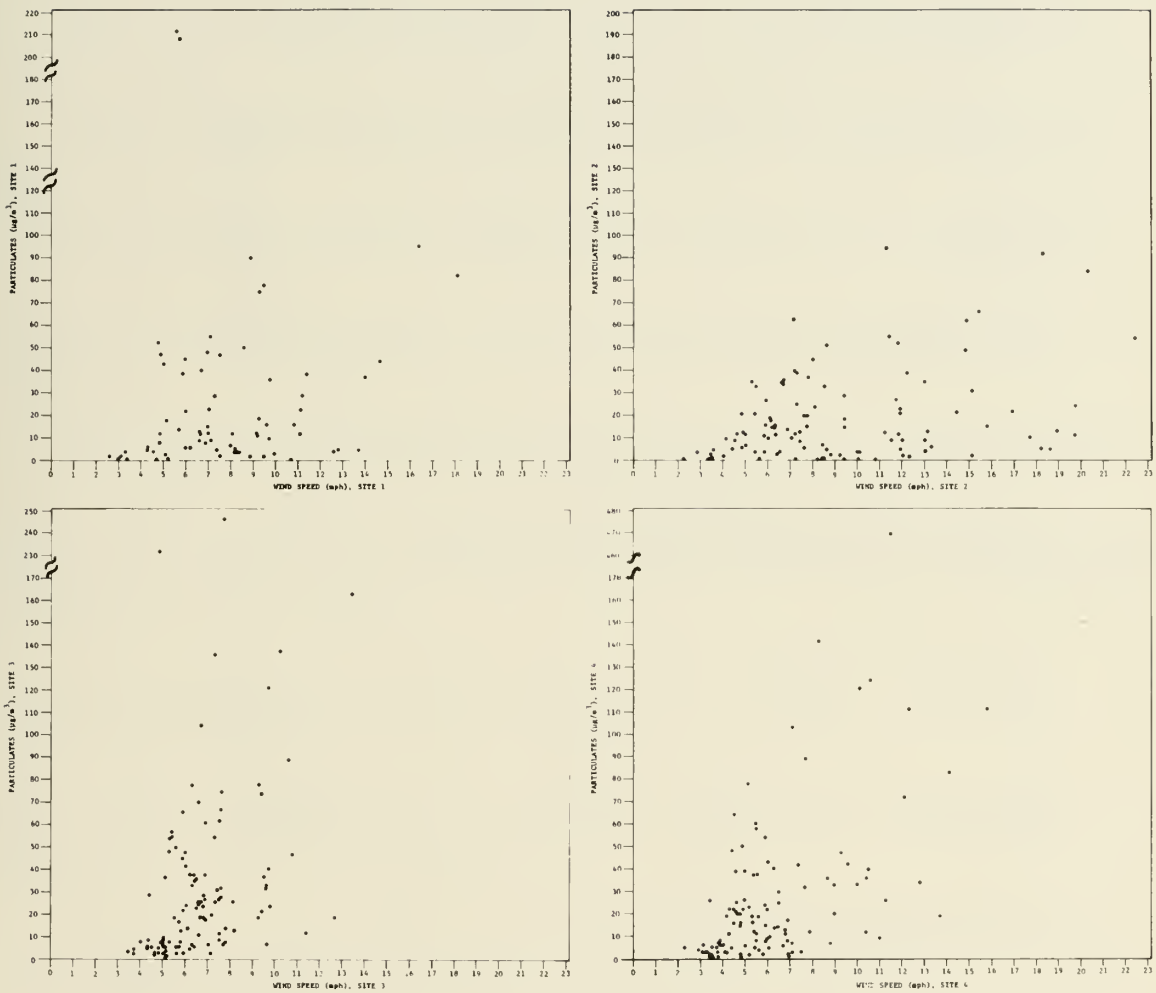


Figure 3-5-12

CORRELATION OF PARTICULATE CONCENTRATIONS AND WIND SPEED AT SITES 1, 2, 3 AND 4, RBOSP

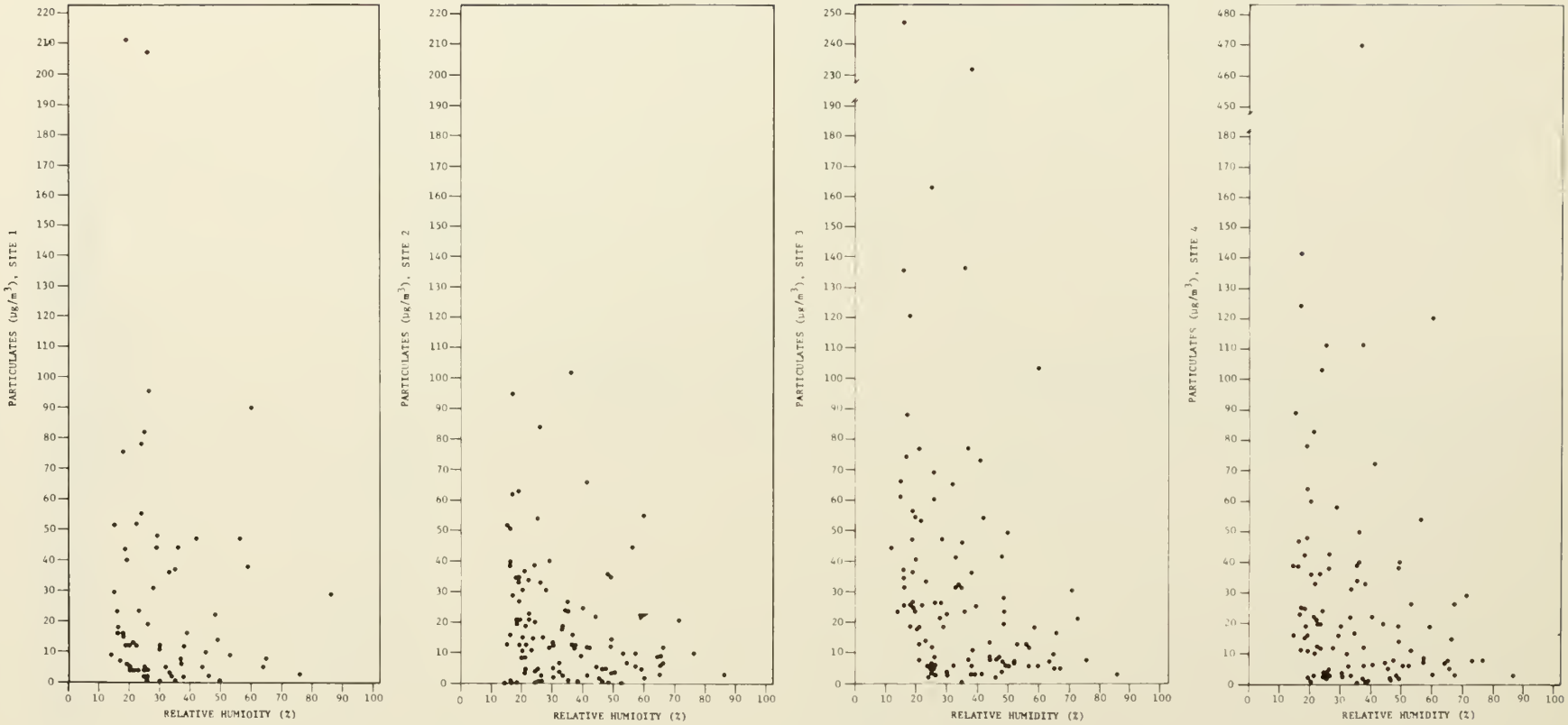


Figure 3-5-13

CORRELATION OF PARTICULATE CONCENTRATIONS AND
RELATIVE HIMIDITY AT SITES 1, 2, 3 AND 4, RBOSP

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CHAPTER 6

METEOROLOGY

SECTION 3
BASELINE CONDITIONS

CHAPTER 6
METEOROLOGY

A baseline meteorological program has been carried out to:

- Satisfy the Oil Shale Lease Stipulations, 1974, and other Federal and State regulations;
- Provide site specific information required in developing design criteria for air quality control;
- Provide pre-development values of atmospheric parameters for project impact assessment;
- Provide local meteorological data required for ecological, hydrological, and water quality assessments; and
- Provide local information to verify/correlate existing data and prediction techniques.

In compliance with the oil shale lease requirements, the central station (Site 1) of the monitoring network is located within 3 km of the proposed plant site and at the anticipated point of maximum air quality impact (Figure 3-6-1). Three remote stations are located at Sites 2, 3, and 4 (Figure 3-6-1) to monitor meteorological and air quality parameters throughout the project area.

Percentage of data recovered for continuously monitored parameters have been computed and updated throughout the baseline data collection. This has been done to show the effort being made to satisfy the Oil Shale Lease Environmental Stipulations. These stipulations state that " . . . the Lessee shall establish a meteorological station in reasonable proximity to each proposed plant site to monitor, at least 95 percent of each lease year during which monitoring is required . . . " The annual, cumulative data recovery percentages by type of parameter are presented in Table 3-6-1.

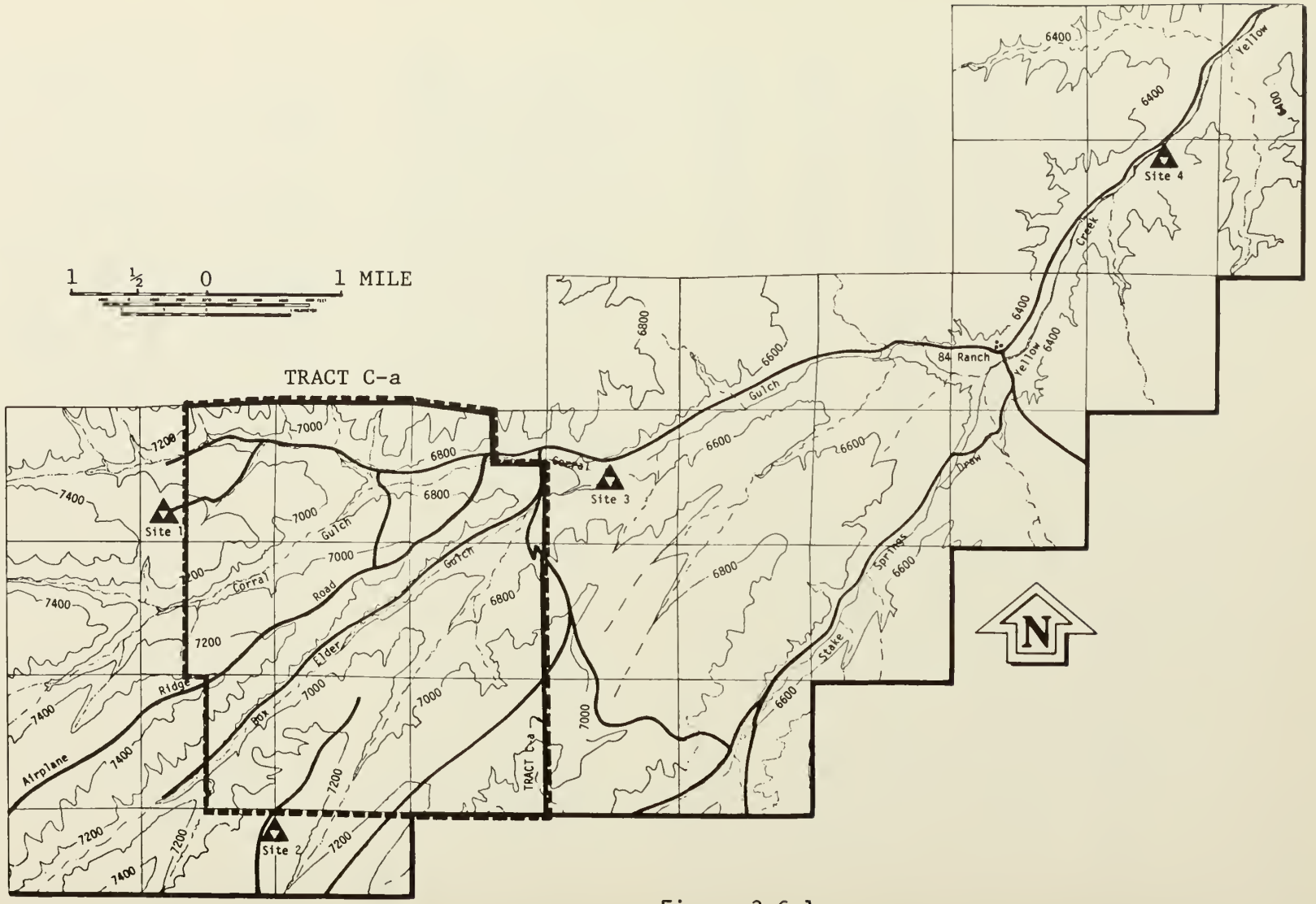


Figure 3-6-1

TOPOGRAPHIC MAP OF AREA AROUND TRACT C-a SHOWING LOCATIONS OF METEOROLOGICAL/AIR QUALITY STATIONS

Table 3-6-1

METEOROLOGY ANNUAL CUMULATIVE PERCENTAGE RECOVERY*
(1 FEBRUARY 1975 THROUGH 31 JANUARY 1976)
RBOSP

Parameter	Annual Percentage of Recovery**
Visibility Measurements	100.0
Precipitation	99.8
Solar Insolation	92.6
Snow Course	100.0
Evaporation	100.0
Wind Speed (WS)	99.0
Wind Direction (WD)	99.1
Air Temperature (AT)	98.8
Relative Humidity (RH)	99.1
Temperature Difference (Δ T, 10-60 m)	98.6
Wind Sigma (σ)	98.4

* Goal: $\geq$ 95%
** If the total operational hours are used for the numerator of the "Monthly Percentage Recovered" equation, the percent data recovered would be larger.

The equation used to determine monthly data recovery percentages is given below.

$$\text{Monthly Percentage Recovered} = \left[\frac{\text{Actual Recovered Data (hours)}}{\text{Total Possible Recovered Data (hours)}}\right] X \left[100\%\right]$$

In this equation, Actual Recovered Data include:

- Data collected, processed and analyzed under quality assurance control;
- Data temporally bracketed by routine calibration data;
- Calibration periods: Although recorded data are not available for analysis or use, the recovery rates are not penalized for critical calibration time; therefore, calibration hours are included as a portion of the actual recovered data hours;
- Force Majeure Periods: Although data are not always reliably recorded during these periods, time of force majeure is included as actual recovered day(s). Force majeure is defined as those conditions that are not practically controllable or avoidable, such as storms, lightning, snow, extreme winds, public power failures, or severe acts of God.

On a monthly basis, the "Monthly Percentage Recovered" is determined for each air quality and meteorological parameter and location combination using this equation.

From "Monthly Percentage Recovered" values a "Percentage Recovered Through the Month" is calculated using the following equation:

$$\text{Percentage Recovered Through the Month} = \left[\frac{\left(\begin{array}{c}\%\text{ present}\\ \text{month*}\end{array}\right)\left(\begin{array}{c}\text{total days}\\ \text{present month}\end{array}\right) + \left(\begin{array}{c}\%\text{ through}\\ \text{previous}\\ \text{month}\end{array}\right)\left(\begin{array}{c}\text{total days}\\ \text{through previous}\\ \text{month}\end{array}\right)}{\text{total days through present month}}\right] X \left[100\%\right]$$

* from equation for Monthly Percentage Recovered

The cumulative percentage by type of air quality parameter, for those sites and locations where the parameter is measured, is calculated by the following equation, using the "Percentage Through the Month" values.

$$\text{Percentage Recovered By Type of Parameter} = \frac{\sum_{1}^{n^*} \text{Percentage Through the Month for Location } n^*}{n^*}$$

n* - numerical count of locations at which parameter is measured.

These annual percentages, in combination with the stringent quality assurances program, satisfy the quality and quantity requirements of the Oil Shale Lease Environmental Stipulations with the exception of solar insolation which was only 2.4% below the designated goal. If the total operational hours had been used for the numerator of the "Monthly Percentage Recovered" equation, solar insolation percentage recovery, as well as the other percentages, would be larger.

Topography in the area consists of a series of ridges sloping from Cathedral Bluffs west of Tract C-a to Piceance Creek east of the tract that are cut by numerous gulches draining toward the northeast. The ridge just west of Tract C-a is at an altitude of about 7,300 ft and slopes to about 6,800 ft northeast of the tract. The deeper gulches have been cut to depths of about 200 ft. The proposed plant site is at an altitude of about 7,200 ft. The

monitoring sites on the ridges (Sites 1 and 2) are situated to sample the commonly occurring southwesterly airflow before it passes over the project area. Sites 3 and 4 are in Corral Gulch and Yellow Creek Gulch, respectively, on the leeward side of the tract.

Reliability of baseline meteorological data is assured by a comprehensive Quality Assurance program, established to meet the requirements specified in 10 CFR 50, Appendix D. Maintenance, operation, calibration, handling, shipping, storage, and inspection procedures are documented. Calibration procedures are traceable to established standards. Calibration schedules are established and rigorously executed. Quality Assurance audits are scheduled on a regular basis to monitor compliance with calibration and equipment maintenance procedures and other elements of the program. Discrepancies are documented and resolved. Any deviations are documented and affected data verified before being incorporated into the data base. The documentation system is program-wide and is continuously up-dated.

Measurements of the baseline meteorological program have been partitioned into the following categories for clarity: lower air studies, upper air studies, and miscellaneous measurements. Lower air studies refer to continuous measurements of wind speed and direction, wind sigma, temperature, and relative humidity made at heights from 10 to 60 m. Upper air studies refer to temporal, discrete measurements of ambient temperature made from an airplane at heights from about 60 m to about 2 km above terrain and measurements of wind speed and direction deduced from pilot balloon soundings at Site 1. Miscellaneous measurements include atmospheric tracer studies, precipitation, evaporation, insolation, noise, and visibility.

An important use of site specific air quality and meteorological data is quantifying an acceptable mathematical diffusion model of the atmosphere which then becomes a tool for predicting ambient concentrations of pollutants resulting from proposed project developments. The meteorological data must be both extensive and accurate so that prediction errors can be kept to a

minimum. The important meteorological data which determine the diffusion capability of the atmosphere are described in Section 9 Chapter 5.

The long range climate of the area surrounding the tract is similar to that of semi-arid steppe regions. The annual precipitation in the area is about 10 to 12 in., but is strongly dependent upon local topography and elevation. Because the entire Piceance Creek area is surrounded by high mountains, many migratory low pressure systems are deflected around the region. Stationary high pressure cells often persist for several days, their passage blocked by the high mountains to the east. As a result, there is a high frequency of clear sunny days with light winds and large diurnal temperature changes. Ambient temperatures are moderate during the spring, summer, and fall seasons with low wintertime minimums. The gradient winds are generally the prevailing westerlies which exist throughout the year and are interrupted by the passage of frontal systems.

Local topography within the Piceance Creek Basin has a much more pronounced affect on surface flows than the macroscale processes. The specific air movements produced by local conditions are often different than those one would expect to be caused by the major gradient flow. There is a tendency for wind velocities to be lowest about dawn, at which time there is little vertical thermal mixing and the lower surface air does not couple with the more freely moving upper air. Conversely, velocities of local winds are greatest between 1300 and 1400 hours MST when the air exhibits its greatest tendency to move vertically due to terrestrial heating, and couples with the faster air moving above it.

In the absence of strong gradient winds, the local terrain produces special meteorological conditions. During warm afternoons, the laterally constricted but vertically expanded air tends to blow up the valley. This flow probably develops simultaneously with anabatic (upslope) winds which result from a greater heating of the valley side with respect to the valley floor. At night there is a reverse process as the colder, more dense air at higher

elevations drains into the depressions. The greater radiative heat loss affecting the higher elevations (especially if they are snow covered) cools the air immediately adjacent to the surface and this sinks into the valley. Downward movements of cold air set in motion by this effect form downslope winds leading to an accumulation of cold, dense, stable air in the valley bottom.

6.1 LOWER AIR STUDIES

Meteorological measurements of the lower air are made at four monitoring sites. Monitoring facilities at Site 1 include a 60-meter meteorological tower instrumented at three levels and a trailer in which data from all four monitoring sites are received, processed, and recorded. Ten-meter meteorological towers (instrumented at the 10-m level) and trailers (in which the data are conditioned, recorded in analog form, converted to digital form and transmitted to the central station at Site 1) are situated at Sites 2, 3, and 4, (Figure 3-5-2). Complete descriptions of the monitoring sites as well as information on instrumentation, calibration and other facets of the data gathering process are provided in the following reports: Progress Reports 2, 3, 4 (RBOSP, 1975a, 1975b), Progress Reports 5 and 6 (RBOSP, 1976b, 1976c) Annual Report (RBOSP, 1976a) and Statement of Work and Organization for Meteorological Systems, Air Quality Systems, and Studies (EG&G, Inc., 1974). Readers desiring further information on methodology or complete data presentations should consult these reports which are on file with the AOSS in Grand Junction, Colorado.

Atmospheric parameters measured for the lower air studies include wind speed and direction, wind sigma (standard deviation of the wind direction variation), air temperature, relative humidity, and temperature difference. Temperature lapse rate is calculated from the temperature difference. The following table shows the measurements made for the lower air studies at Site 1:

Level (meters)	Wind Speed	Wind Direction	Temp.	Relative Humidity	Temp. Diff.	Wind Sigma
10	x	x	x	x	x	x
30	x	x	x			
60	x	x	x		x	

Temperature difference (ΔT) is the ambient temperature at 10-m level minus that at the 60-m level. At each of the remote sites (Sites 2, 3, and 4)

wind speed, wind direction, and air temperature are measured at the 10-m level.

Major elements of the data handling system for the lower air studies are signal conditioning, analog and manual data recording, and digital processing and recording.

A. Objectives - The lower air studies describe the airflow characteristics and near-surface atmospheric stability throughout the project area on a continuous basis. Atmospheric stability is used here to describe the ability of the atmosphere to suppress (stable) or enhance (unstable) turbulent air tending to disperse effluents. The data taken are representative for the period of record and can be used with long-term records from nearby weather stations to extend the period of validity and/or representativeness. This information is used to describe existing atmospheric conditions and provide the primary numerical input to atmospheric diffusion models which are used for prediction of air quality impact of the various project emissions. Wind sigma is also used to estimate the amount of turbulence available in the atmosphere for dispersing project emissions.

B. Methods - The configuration of each of the monitoring sites, showing the tower structures, orientation of instruments, relationships between tower and other buildings, and general exposure of the instruments, along with detailed methodologies can be found in the RBOSP reports referenced earlier. Meteorological measurements made and the basic equipment and sensors used are shown in Table 3-6-2.

C. Literature Review - The meteorological dispersion potential of the study area is characterized by the local topography and climatology. The Piceance Creek Basin, in which Tract C-a is situated, lies between the Colorado and White Rivers on the western slope of the Rocky Mountains at an average elevation of approximately 7,000 ft above MSL. Immediately to the east of the basin is a region reaching to more than 11,000 ft above MSL, the so-called Flat Tops out of which the White River drains. To the southeast lies a large

Table 3-6-2

METEOROLOGICAL INSTRUMENTS, RBOSP

Parameter	Instrument
Wind Speed	Climet Model 011-1 Anemometer
Wind Direction	Climet Model 012-30 Transmitter†
Air Temperature*	Rosemount Model 146-MA-100-F Platinum Resistance Sensor mounted in a Climet Model 016-10 Vane Aspirated Temperature Shield
Air Temperature and Temperature Difference**	Rosemount Model 171 BM Temperature Sensor and R.M. Young Model 43404 Motor Aspirated Gill Radiation Shield
Relative Humidity	Weather Measure Model H 352 Solid State Relative Humidity Sensor

*Used at 10-m level at Sites 2, 3, and 4 and at 30-m level at Site 1.

**Used at 10 and 60-m levels at Site 1.

† The signal from this instrument is analyzed by the computer to obtain wind sigma.

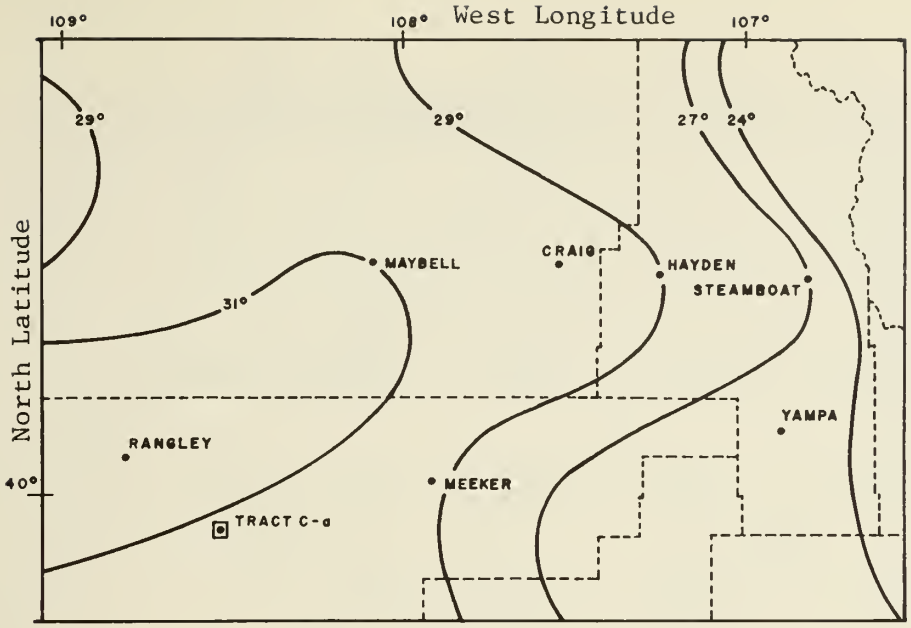
high massif which drains to the Colorado River and its tributaries. The surface flow in the region of the tract drains into the White River. Cathedral Bluffs lie to the west of the tract. The western face of the bluffs rises abruptly from Douglas Creek Valley. The eastern face slopes gently downward toward the tract. The Piceance Creek Basin is dissected by a number of NNE-draining valleys.

The long range climate of the basin is similar to that of semi-arid steppe regions (Engineering Science, Inc., 1974). Average annual precipitation in the area is 10 to 12 in. Topography and elevation, however, contribute to widely-ranging variations in precipitation. Migratory low pressure systems are frequently deflected around the region by the surrounding mountains. Stagnant high pressure cells often prevail for several days, their passage blocked by the high mountains to the east. The result is a high frequency of clear sunny days with light winds and large diurnal temperature changes. The temperature extremes of the region show wide variations on both annual and diurnal time cycles. Isopleths of January and July temperature extremes are shown in Figures 3-6-2 through 3-6-3 (Unpublished Data Summary). Average temperatures are frequently below freezing for weeks at a time in the winter. The valleys exhibit wide diurnal temperature changes, caused in part by drainage winds*, and are often significantly colder than surrounding terrain during the winter. Table 3-6-3 presents surface temperature data from Environmental Data Service stations with long record periods in the area (CER Geonuclear, 1971). Little Hills is of particular interest since it is closest to the project area.

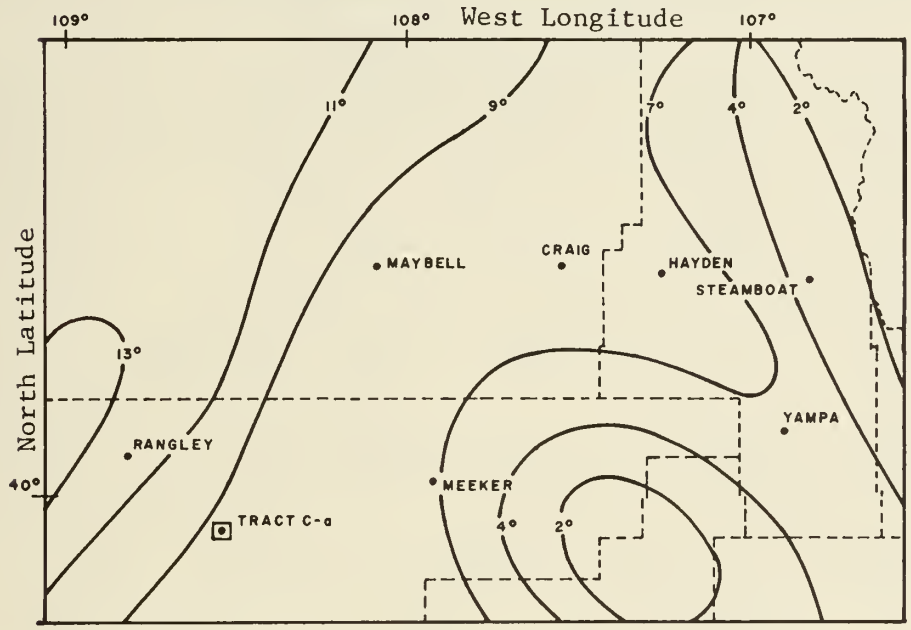
The Rocky Mountains to the east and the Sierra Nevada Mountains to the west

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* On a night of clear skies with little pressure gradient, terrestrial radiation from the surface causes a layer of cold air to form near the ground, with an associated inversion of temperature. If the ground is sloping, the air close to the ground is colder than air at the same level but at some horizontal distance. Downslope gravitational flow of the colder, denser air beneath the warmer, lighter air results and comprises the drainage wind.



MAXIMUM AIR TEMPERATURE

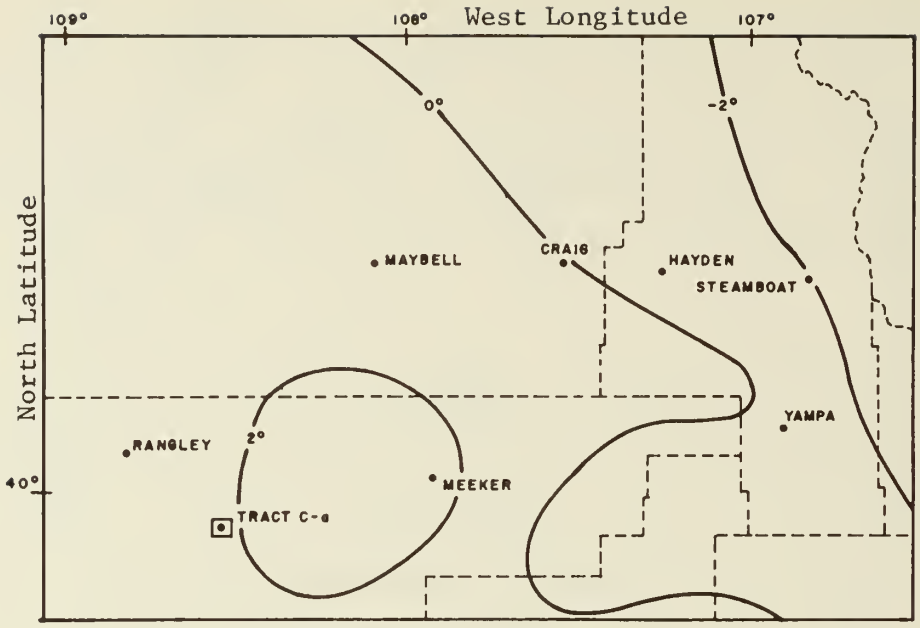


MINIMUM AIR TEMPERATURE

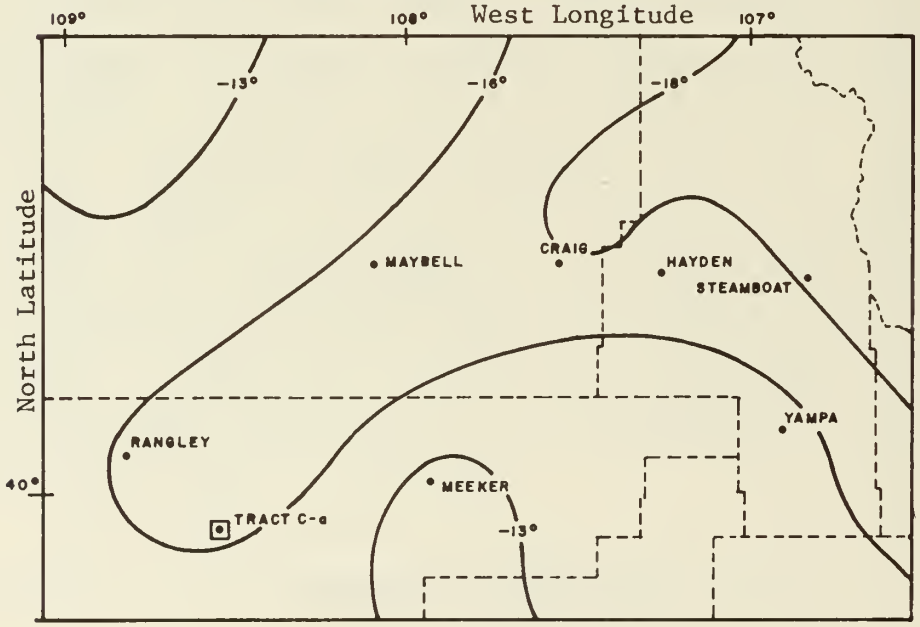
Figure 3-6-2

ISOPLETHS OF AVERAGE MAXIMUM AND MINIMUM JULY TEMPERATURES (°C) IN NORTHWEST COLORADO

Source: Unpublished Data Summary



MAXIMUM AIR TEMPERATURE



MINIMUM AIR TEMPERATURE

Figure 3-6-3

ISOPLETHS OF AVERAGE MAXIMUM AND MINIMUM JANUARY TEMPERATURES(°C) IN NORTHWEST COLORADO

Source: Unpublished Data Summary

Table 3-6-3

SURFACE CLIMATOLOGICAL TEMPERATURE SUMMARY (THROUGH 1960)
AT SELECTED SITES IN NORTHWEST COLORADO
TEMPERATURE (°F)

Station	Temperature	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Craig	Mean	17.2	21.8	30.8	42.5	51.4	59.3	66.5	64.8	56.6	45.5	31.0	22.6	42.5
40°31' 107°33'	Mean Max.	32.9	37.0	44.5	57.6	68.3	77.9	86.1	83.8	76.3	63.6	46.7	37.1	59.3
6285 ft	Mean Min.	1.5	6.7	16.9	27.3	34.6	40.7	46.9	45.8	37.0	27.4	15.3	8.2	25.7
	Highest	53	58	71	81	87	100	99	96	93	84	71	64	100
	Lowest	-40	-43	-24	-2	14	21	31	28	17	9	-19	-31	-43
Little Hills	Mean	21.7	24.6	32.0	41.9	50.5	58.7	65.3	63.4	56.0	44.4	31.2	24.4	42.8
40°00' 108°12'	Mean Max.	38.3	41.8	47.4	59.1	68.8	79.5	86.3	83.4	77.8	65.0	48.8	41.2	61.5
6148 ft	Mean Min.	5.0	7.8	16.6	24.5	32.3	37.9	44.4	43.7	34.2	23.7	13.7	7.7	24.3
	Highest	60	64	70	80	87	97	98	98	95	91	68	69	98
	Lowest	-35	-32	-25	7	13	20	30	28	12	-1	-27	-30	-35
Meeker	Mean	20.9	25.0	33.4	43.4	51.6	59.7	65.7	64.0	56.1	45.4	33.2	22.8	43.4
40°02' 107°54'	Mean Max.	36.2	40.2	47.3	59.0	69.2	79.5	85.4	82.9	75.5	63.2	48.9	37.1	60.4
6242 ft	Mean Min.	5.4	9.8	19.5	27.8	33.9	39.8	46.0	45.1	36.7	27.5	17.6	8.3	26.5
	Highest	61	63	72	86	93	102	103	99	94	86	73	65	103
	Lowest	-43	-38	-24	-5	14	20	26	29	14	-6	-25	-36	-43
Rangeley	Mean	18.4	23.7	35.2	47.4	57.4	67.0	73.6	70.4	62.2	49.6	33.6	22.6	46.8
40°05' 108°47'	Mean Max.	33.2	39.2	50.3	63.6	74.9	86.5	93.0	89.3	82.9	69.3	49.8	37.0	64.1
5216 ft	Mean Min.													
	Highest	53	63	74	86	95	104	102	101	98	86	72	57	104
	Lowest	-37	-32	-8	11	24	30	39	32	25	8	-5	-20	-37

Source: CER Geonuclear, 1971

influence the climate. Moist air from the Gulf of Mexico is blocked by the Rocky Mountains while the Sierra Nevada Mountains interrupt the flow of Pacific maritime moisture. Both flows lose most of their moisture in passing the respective ranges before reaching the oil shale tract.

The winds of the area are generally westerly throughout the year and are interrupted only by the passage of frontal systems (Environmental Data Service, 1939-1975b).

The proximity of the tract to Cathedral Bluffs, the general downslope of the region to the northeast, and the deep gulches effectively channel the surface winds and thereby decouple the upper level flows from the surface flows much of the time (Nelson, 1975). Several studies (CER Geonuclear, 1971; Engineering Science, Inc., 1974; and Nelson, 1975), have shown that airflow within the canyons of the Piceance Creek Basin are influenced by drainage winds in their respective channels, whereas winds measured atop the ridge-like portions of the basin follow the gradient wind* regime closely. It can be inferred that these drainage winds occur in conjunction with temperature inversions and also that the temperature lapse rate is less within the valley than above the ridge regions as shown in Table 3-6-4.

D. Data Summary and Discussion - The data summaries for February 1975 through January 1976 are presented. The seasonal breakdown (by months) used is winter 1975 (February), spring 1975 (March, April, May), summer 1975 (June, July, August), fall 1975 (September, October, November), and winter 1975-1976 (December, January). The seasonal and annual summaries of minimum, maximum and mean values of the meteorological parameters measured at each site, i.e., wind speed, wind direction sigma, air temperature, temperature difference, and relative humidity are presented in Tables 3-6-5

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* A gradient wind blows parallel to lines of constant atmospheric pressure with a balance among centrifugal, Coriolis, and pressure-gradient forces per unit mass.

Table 3-6-4

INVERSION STATISTICS OVER THE PICEANCE CREEK BASIN
USING DATA COLLECTED OVER SEASONAL 15-DAY INTENSIVE STUDY PERIODS

Season	Frequency of Inversions*	Frequency of Inversions Extending Above Plateau	Mean Height of Inversions Existing Above Plateau (Feet Above Plateau 7200 ft MSL)	Mean Lapse Rate Within Inversions Below Plateau (^{o}C/100m)	Mean Lapse Rate Within Inversions Above Plateau (^{o}C/100m)
Fall 1974	100%	50%	750	-2.38	-1.60
Winter 1975	60%	27%	725	-3.86	-0.42
Spring 1975	47%	20%	450	-1.84	-0.69
Summer 1975	100%	53%	1,000	-2.99	-0.44

*Percentage of days on which at least one inversion was observed

Source: Nelson, 1975

through 3-6-10. The minimums and maximums listed are the individual hourly averages.

1. Wind Speed and Direction - The mean wind speed at Site 1 (10-m level) was about 1.5 mph less than at Site 2 (Tables 3-6-5 through 3-6-10). Although Sites 1 and 2 are at about the same elevation (7,400 ft above MSL), the local terrain at Site 2 is flatter than that at Site 1. The Site 2 monitoring location is the highest point within a radius of approximately 1 km. The 10-m level of the main meteorological tower at Site 1 is approximately 50 m lower than the elevation of several knolls within several hundred meters to the southwest. The increased terrain influence at Site 1 is responsible for the lower mean wind speed.

Mean wind speeds at Sites 3 and 4 averaged lower values than those at Sites 1 and 2 (Tables 3-6-5 through 3-6-10). Sites 3 and 4, below ridge levels, are situated in the approximate centers of Corral Gulch and Yellow Creek Gulch at elevations of 6,570 and 6,280 ft above MSL. Corral Gulch lies in a west to east direction. Yellow Creek Gulch lies in a south-southwest to north-northeast direction.

Wind speed and direction joint frequency distributions of hourly averages from Sites 1 and 2 (10-m level) are similar in configuration (Figures 3-6-4 through 3-6-9). Winds at Sites 1 and 2 (10-m level) were predominantly from the southwesterly quadrant. At Site 1, the reduced frequency of occurrence of southwest winds relative to south-southwest and west-southwest winds are the result of the influence from a small knoll about 200 m southwest of the site and 50 m higher.

Extreme terrain-induced wind channeling effects exist at Sites 3 and 4. Prevailing winds at Site 3 are from the west (Figures 3-6-4 through 3-6-9) which is in agreement with the westerly course of Corral Gulch. The prevailing winds at Site 4 are from the south-southwest or southwest (Figures 3-6-4 through 3-6-9), corresponding to the orientation of Stake Springs Draw and Yellow Creek. In addition to the terrain-induced channeling of the

Table 3-6-5

SUMMARY OF WINTER (FEBRUARY) 1975 MINIMUM, MEAN AND MAXIMUM VALUES OF METEOROLOGICAL PARAMETERS MEASURED ON TRACT C-a, RBOSP

Parameter*	Units	Minimum**	Maximum**	Mean
		Site 1		
Wind Speed (10 meters)	MPH	0.66	28.68	7.54
Wind Speed (30 meters)	MPH	0.56	32.19	8.76
Wind Speed (60 meters)	MPH	0.63	35.76	10.27
Air Temperature (10 meters)	^{o}C	-17.60	7.08	-3.86
Air Temperature (30 meters)	^{o}C	-17.8	6.14	-4.44
Temperature Difference (10 to 60 meters)	^{o}C	-2.08	1.15	0.17
Relative Humidity (10 meters)	%	16.64	92.67	51.78
		Site 2		
Wind Speed (10 meters)	MPH	0.58	34.51	9.25
Air Temperature (10 meters)	^{o}C	-17.80	7.27	-4.37
		Site 3		
Wind Speed (10 meters)	MPH	0.59	20.71	6.23
Air Temperature (10 meters)	^{o}C	-21.50	8.23	-5.38
		Site 4		
Wind Speed (10 meters)	MPH	0.40	22.24	5.61
Air Temperature (10 meters)	^{o}C	-27.24	9.23	-5.68

*wind direction sigma measurements were not begun until the summer quarter
**hourly averages

Table 3-6-6

SUMMARY OF SPRING 1975 (MARCH, APRIL, MAY)
MINIMUM, MEAN, AND MAXIMUM VALUES OF METEOROLOGICAL PARAMETERS
MEASURED ON TRACT C-a, RBOSP

Parameter*	Units	Minimum**	Maximum**	Mean
		Site 1		
Wind Speed (10 meters)	MPH	0.56	30.82	8.74
Wind Speed (30 meters)	MPH	0.56	39.12	10.50
Wind Speed (60 meters)	MPH	0.53	43.04	12.22
Air Temperature (10 meters)	°C	-20.48	21.61	2.67
Air Temperature (30 meters)	°C	-20.97	20.37	1.96
Temperature Difference (10 to 60 meters)	°C	-2.57	2.09	0.27
Relative Humidity (10 meters)	%	16.19	93.12	46.75
		Site 2		
Wind Speed (10 meters)	MPH	0.57	33.84	10.45
Air Temperature (10 meters)	°C	-21.44	21.15	2.02
		Site 3		
Wind Speed (10 meters)	MPH	0.06	21.80	6.98
Air Temperature (10 meters)	°C	-24.35	23.11	1.96
		Site 4		
Wind Speed (10 meters)	MPH	0.00	28.63	6.96
Air Temperature (10 meters)	°C	-27.02	24.39	2.36

*wind direction sigma measurements were not begun until the summer quarter
**hourly averages

Table 3-6-7

SUMMARY OF SUMMER 1975 (JUNE, JULY, AUGUST)
MINIMUM, MEAN, AND MAXIMUM VALUES OF METEOROLOGICAL PARAMETERS
MEASURED ON TRACT C-a, RBOSP

Parameter	Units	Minimum*	Maximum*	Mean
		Site 1		
Wind Speed (10 meters)	MPH	0.70	30.79	7.58
Wind Speed (30 meters)	MPH	0.57	37.05	8.85
Wind Speed (60 meters)	MPH	0.56	41.05	10.19
Wind Direction Sigma (10 meters)	Degrees	0.01	59.26	12.17
Air Temperature (10 meters)	^{o}C	1.40	30.07	17.29
Air Temperature (30 meters)	^{o}C	1.05	27.00	16.85
Temperature Difference (10 to 60 meters)	^{o}C	-4.69	4.74	0.14
Relative Humidity (10 meters)	%	10.00	86.72	25.52
		Site 2		
Wind Speed (10 meters)	MPH	0.62	36.70	9.06
Air Temperature (10 meters)	^{o}C	1.47	27.47	16.86
		Site 3		
Wind Speed (10 meters)	MPH	0.96	29.90	7.10
Air Temperature (10 meters)	^{o}C	-2.39	28.97	15.50
		Site 4		
Wind Speed (10 meters)	MPH	0.59	31.23	6.20
Air Temperature (10 meters)	^{o}C	-2.97	33.14	16.82

*hourly averages

Table 3-6-8

SUMMARY OF FALL 1975 (SEPTEMBER, OCTOBER, NOVEMBER)
MINIMUM, MEAN, MAXIMUM VALUES OF METEOROLOGICAL PARAMETERS
MEASURED ON TRACT C-a, RBOSP

Parameter	Units	Minimum*	Maximum*	Mean
		Site 1		
Wind Speed (10 meters)	MPH	0.59	28.53	7.76
Wind Speed (30 meters)	MPH	0.57	36.16	9.03
Wind Speed (60 meters)	MPH	0.56	40.64	10.68
Wind Direction Sigma (10 meters)	Degrees	0.96	45.00	11.99
Air Temperature (10 meters)	^{o}C	-15.80	24.83	7.50
Air Temperature (30 meters)	^{o}C	-15.90	23.60	7.08
Temperature Difference (10 to 60 meters)	^{o}C	-4.31	2.09	0.03
Relative Humidity (10 meters)	%	13.00	91.20	33.62
		Site 2		
Wind Speed (10 meters)	MPH	0.10	34.85	8.63
Air Temperature (10 meters)	^{o}C	-16.00	24.45	7.20
		Site 3		
Wind Speed (10 meters)	MPH	0.58	22.30	6.73
Air Temperature (10 meters)	^{o}C	-21.00	27.02	5.46
		Site 4		
Wind Speed (10 meters)	MPH	0.54	29.56	5.76
Air Temperature (10 meters)	^{o}C	-25.90	28.35	4.85

*hourly averages

Table 3-6-9

SUMMARY OF WINTER 1975-1976 (DECEMBER, JANUARY)
MINIMUM, MEAN, MAXIMUM VALUES OF METEOROLOGICAL PARAMETERS
MEASURED ON TRACT C-a, RBOSP

Parameter	Units	Minimum*	Maximum*	Mean
		Site 1		
Wind Speed (10 meters)	MPH	0.59	26.93	6.33
Wind Speed (30 meters)	MPH	0.58	31.10	7.14
Wind Speed (60 meters)	MPH	0.57	33.06	8.60
Wind Direction Sigma (10 meters)	Degrees	1.39	33.27	10.82
Air Temperature (10 meters)	^{o}C	-21.10	8.03	- 3.09
Air Temperature (30 meters	^{o}C	-22.10	7.86	- 3.41
Temperature Difference (10 to 60 meters)	^{o}C	- 2.51	6.22	- 0.05
Relative Humidity (10 meters)	%	16.34	89.56	31.31
		Site 2		
Wind Speed (10 meters)	MPH	0.56	31.77	7.15
Air Temperature (10 meters)	^{o}C	-21.40	8.57	- 3.31
		Site 3		
Wind Speed (10 meters)	MPH	0.53	21.46	5.27
Air Temperature (10 meters)	^{o}C	-28.20	10.24	- 5.62
		Site 4		
Wind Speed (10 meters)	MPH	0.50	18.07	4.28
Air Temperature (10 meters)	^{o}C	-33.30	11.44	- 6.92

*hourly averages

Table 3-6-10

SUMMARY OF ANNUAL (FEBRUARY 1975 THROUGH JANUARY 1976)
MINIMUM, MEAN, MAXIMUM VALUES OF METEOROLOGICAL PARAMETERS
MEASURED ON TRACT C-a, RBOSP

Parameter	Units	Minimum*	Maximum*	Mean
		Site 1		
Wind Speed (10 meters)	MPH	0.56	30.82	7.72
Wind Speed (30 meters)	MPH	0.56	39.12	9.04
Wind Speed (60 meters)	MPH	0.53	43.04	10.59
Wind Direction Sigma (10 meters)	Degrees	0.01	59.26	11.77
Air Temperature (10 meters)	^{o}C	-21.10	30.07	6.08
Air Temperature (30 meters)	^{o}C	-22.10	27.00	5.56
Temperature Difference (10 to 60 meters)	^{o}C	- 4.69	6.22	0.11
Relative Humidity (10 meters)	%	10.00	93.12	35.99
		Site 2		
Wind Speed (10 meters)	MPH	0.10	36.70	9.08
Air Temperature (10 meters)	^{o}C	-21.44	27.47	5.52
		Site 3		
Wind Speed (10 meters)	MPH	0.06	29.90	6.61
Air Temperature (10 meters)	^{o}C	-28.20	28.97	4.33
		Site 4		
Wind Speed (10 meters)	MPH	0.00	31.23	5.92
Air Temperature (10 meters)	^{o}C	-33.30	33.14	4.39

*hourly averages

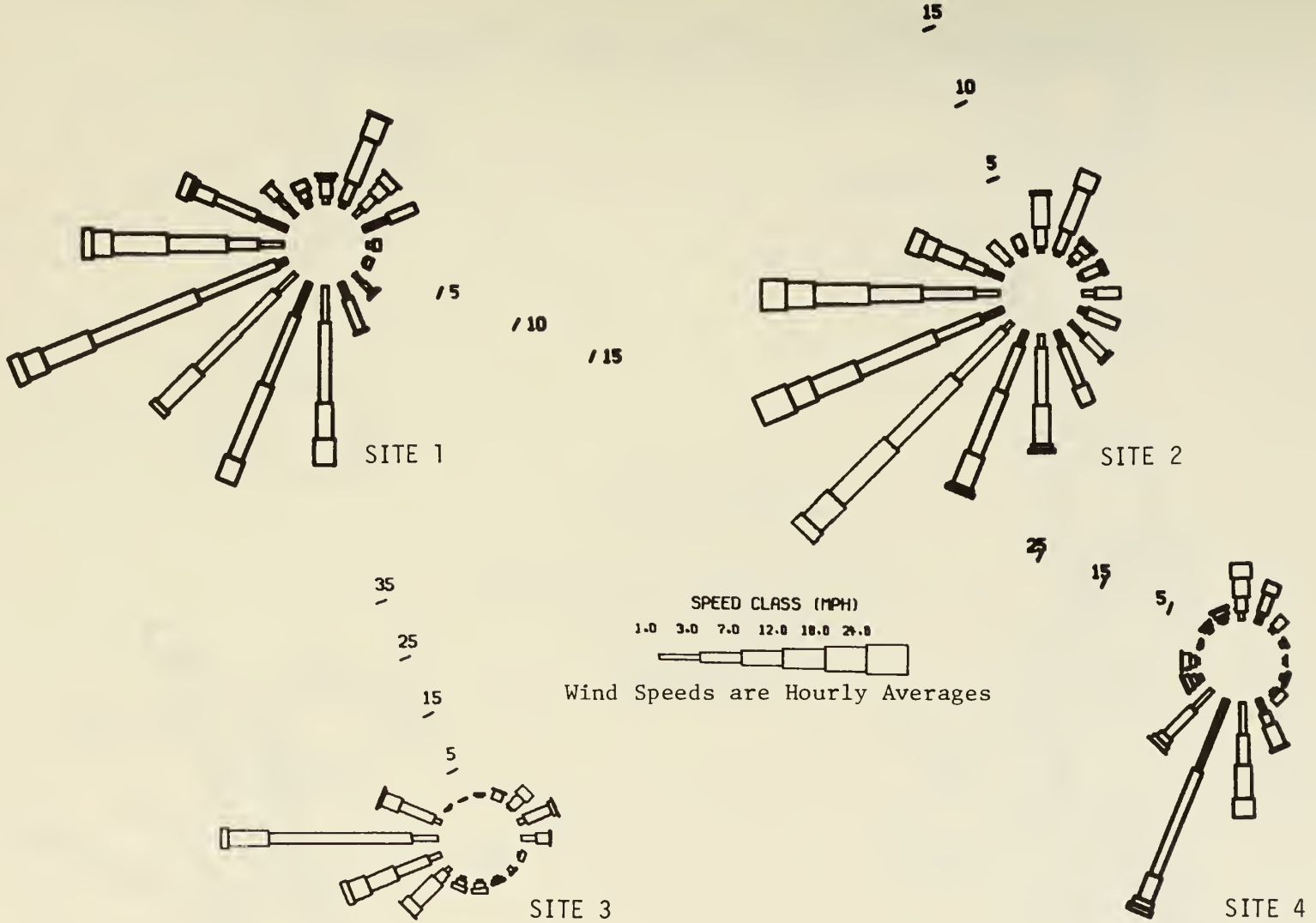


Figure 3-6-4

WINTER 1975 (FEBRUARY) WIND ROSES FOR THE 10-METER LEVEL FOR SITES 1, 2, 3 and 4, RBOSP

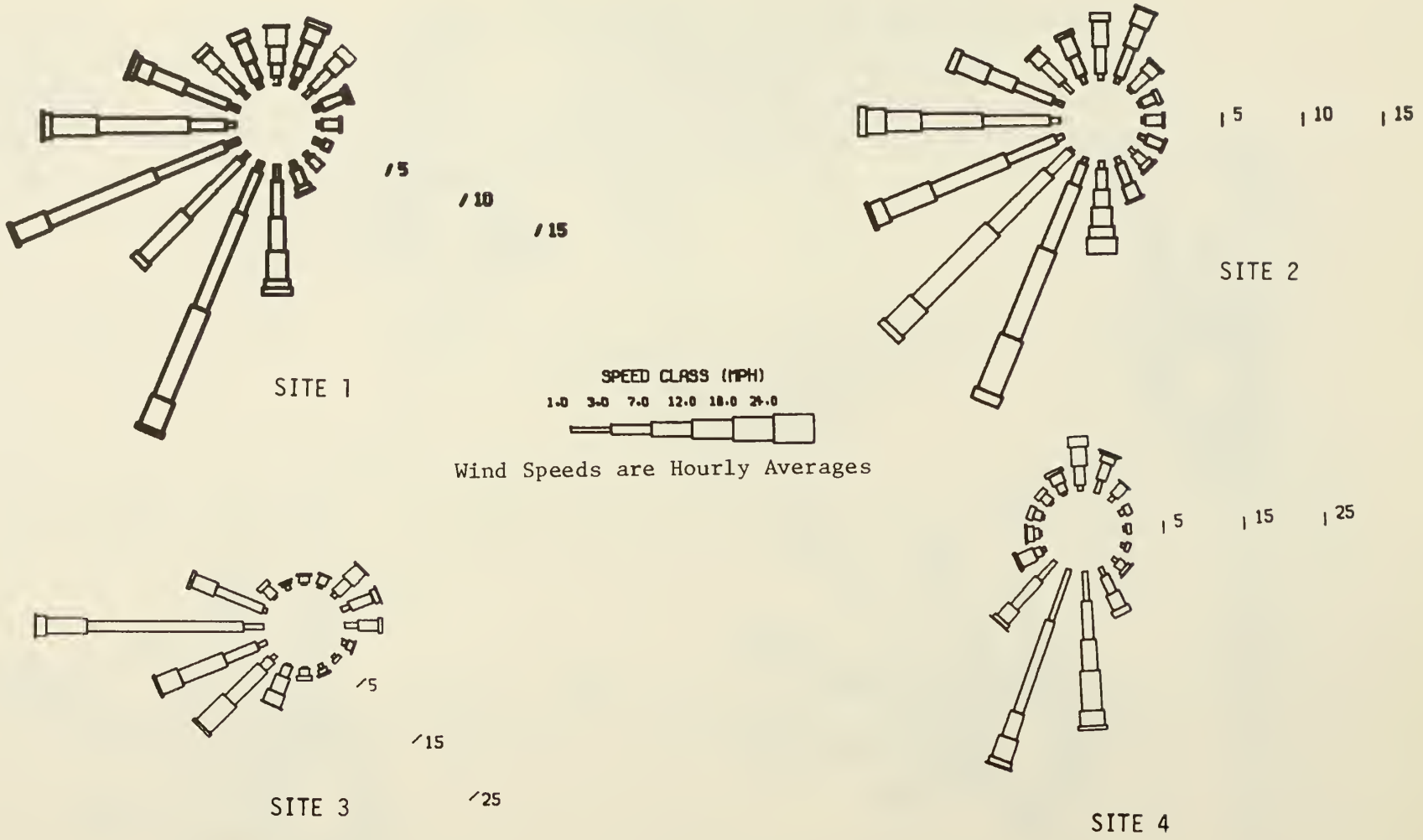


Figure 3-6-5

SPRING 1975 (MARCH, APRIL, MAY) WIND ROSES FOR THE 10-METER LEVEL FOR SITES 1, 2, 3 and 4, RBOSP

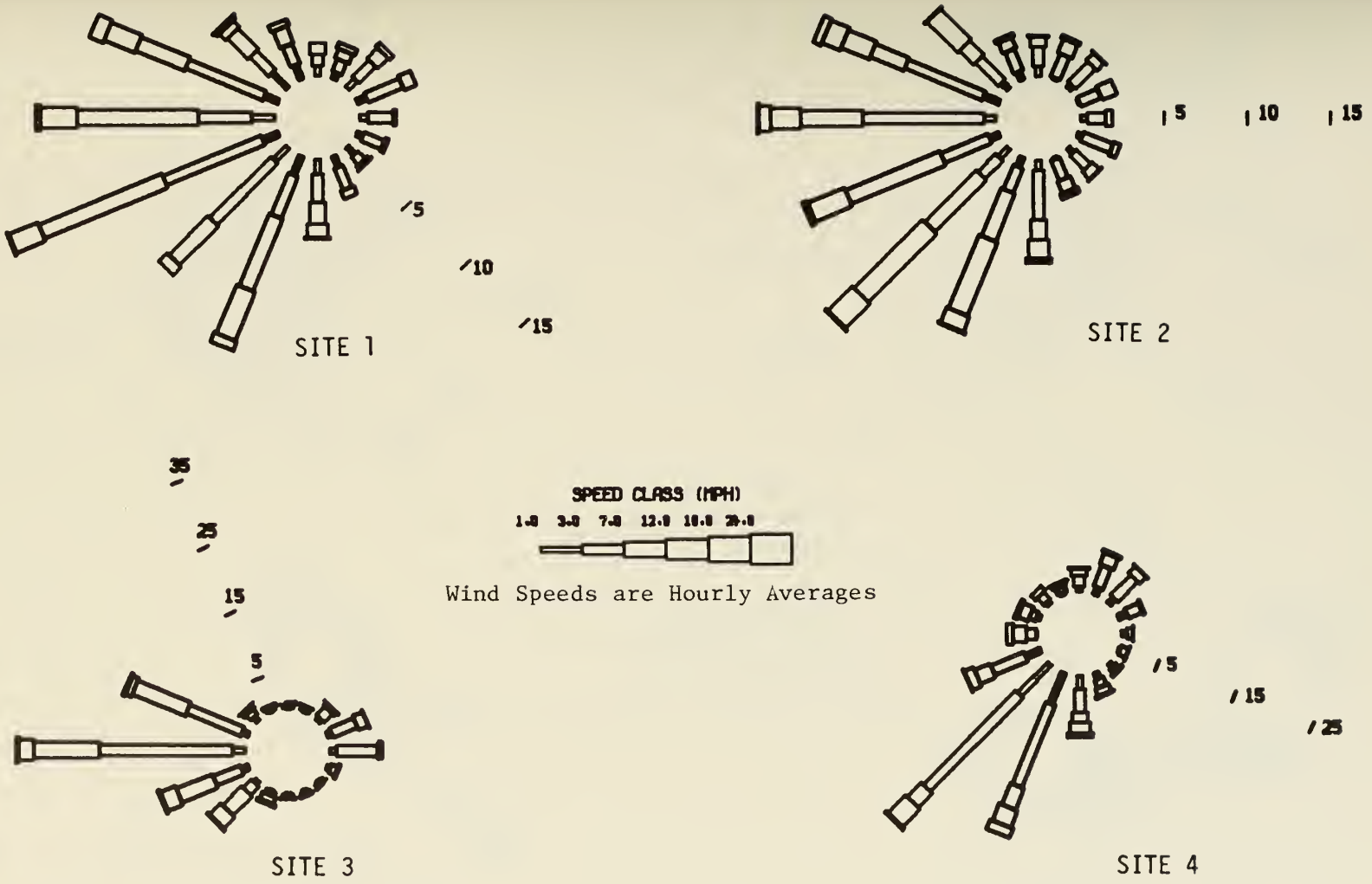


Figure 3-6-6

SUMMER 1975 (JUNE, JULY, AUGUST) WIND ROSES FOR THE 10-METER LEVEL FOR SITES 1, 2, 3, AND 4, RBOSP

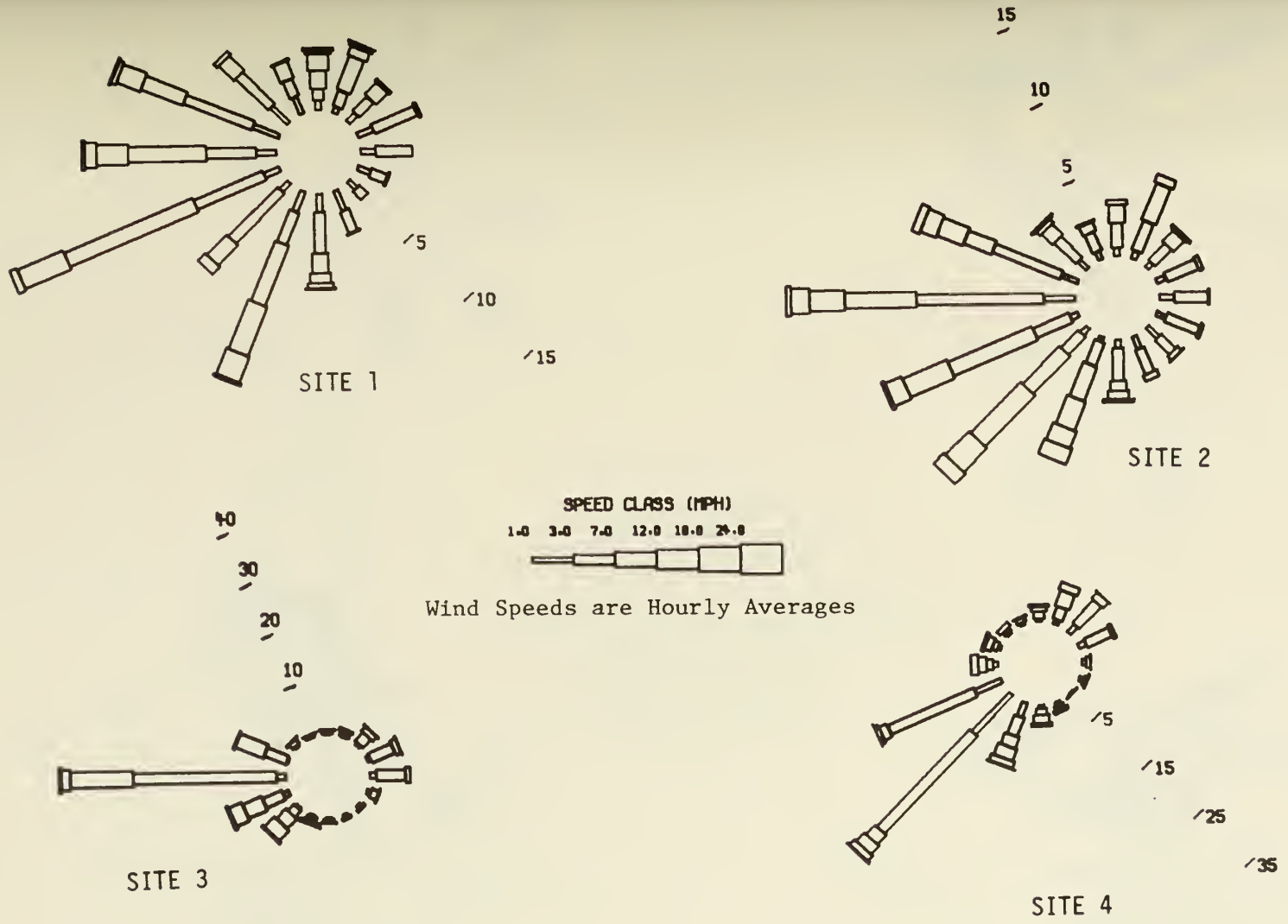


Figure 3-6-7

FALL 1975 (SEPTEMBER, OCTOBER, NOVEMBER) WIND ROSES FOR THE 10-METER LEVEL FOR SITES 1, 2, 3, AND 4, RBOSP

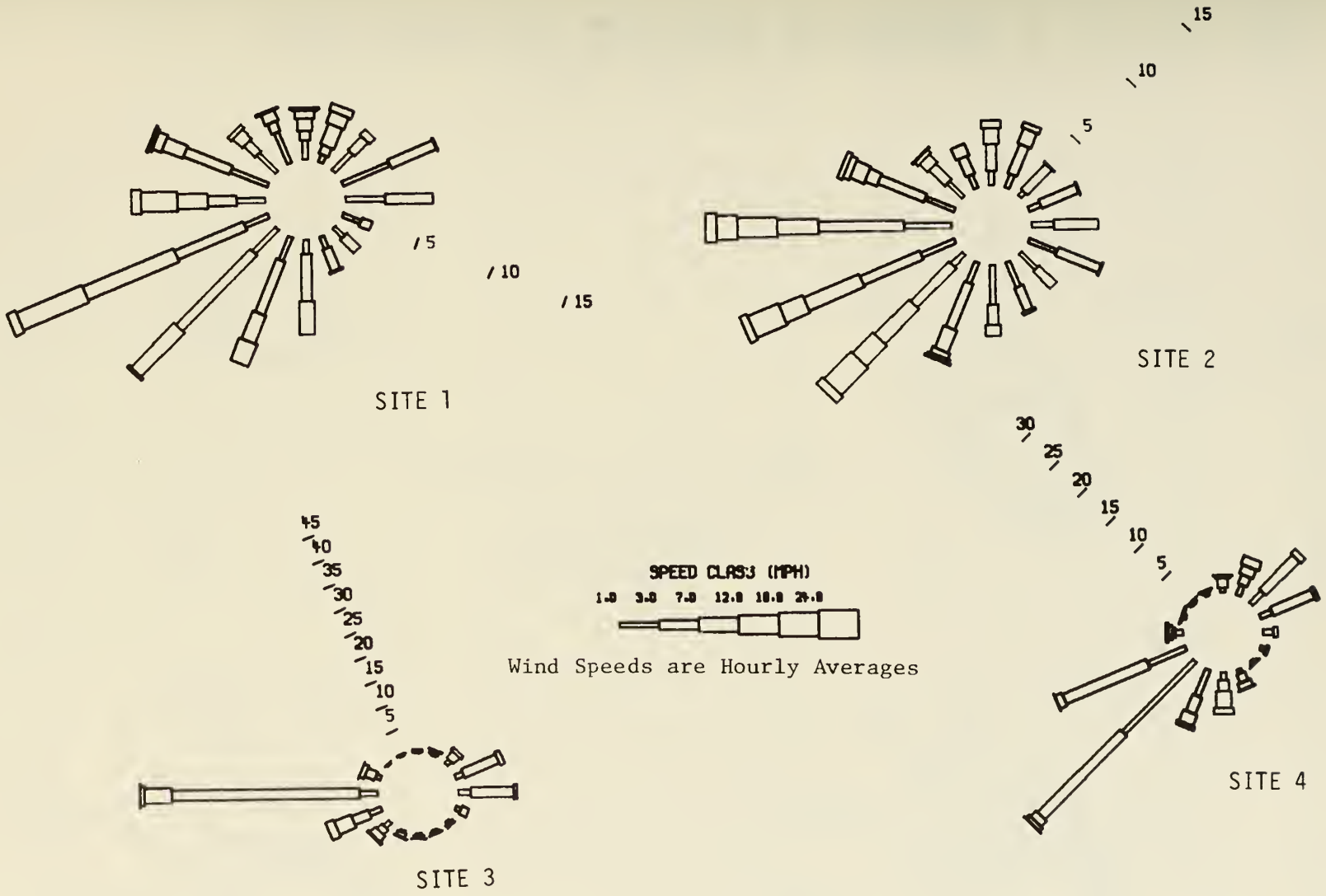
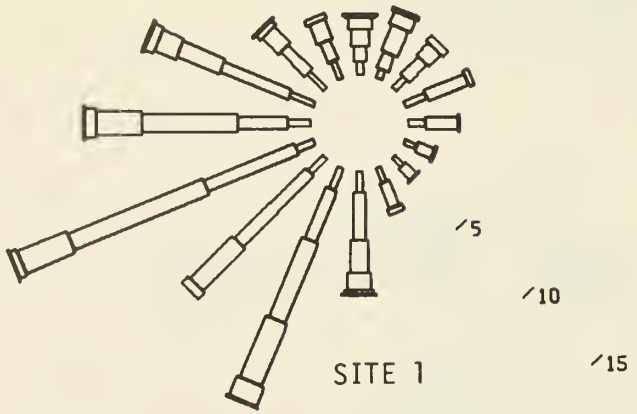
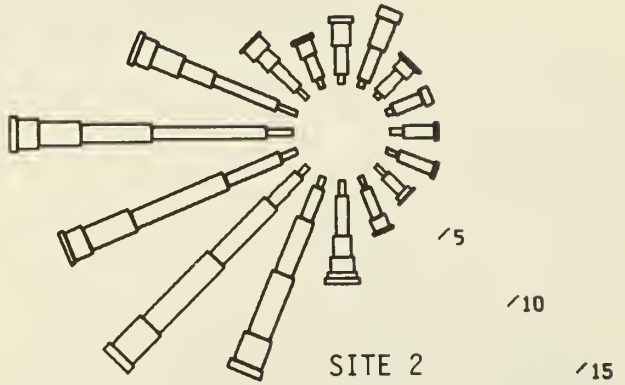
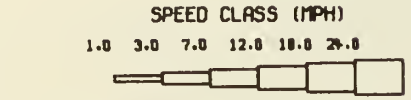


Figure 3-6-8

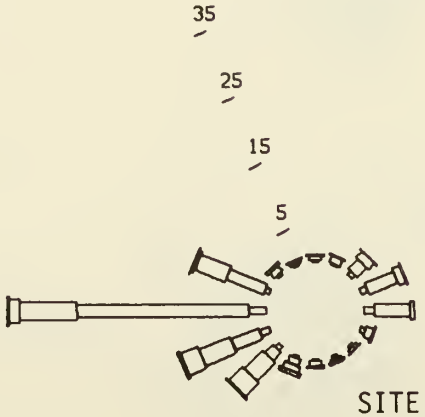
WINTER 1975-1976 (DECEMBER, JANUARY) WIND ROSES FOR THE 10-METER LEVEL FOR SITES 1, 2, 3, AND 4, RBOSP







Wind Speeds are Hourly Averages



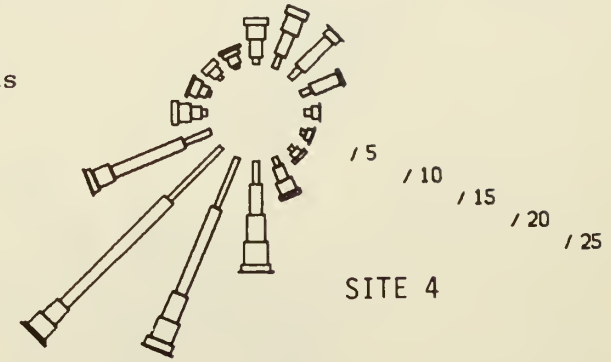


Figure 3-6-9

ANNUAL (FEBRUARY 1975 THROUGH JANUARY 1976) WIND ROSES
FOR THE 10-METER LEVEL FOR SITES 1, 2, 3, AND 4, RBOSP

winds at Sites 3 and 4, valley drainage winds also contribute to the direction frequency.

A diurnal variation in wind direction at the valley sites (3 and 4) is apparent in the recorded data. During the period from about 1100 to 1700 MST, some up-valley flow occurs. This up-valley flow opposes the upper-air wind regime. By 1700 to 1900 MST, up-valley flow slows and there is a transition to down-valley flow. As would be expected, the transition is not well defined. From 1900 MST throughout the night to about 0600 MST the flow is almost always down-valley. The morning transition to up-valley flow usually occurs between 0600 and 1100 MST. This diurnal pattern is disrupted by convective storms and frontal passages.

Table 3-6-11 shows the monthly, seasonal and annual maximum, mean, and minimum wind speed for each site. Figure 3-6-10 shows the maximum, minimum and mean variation in wind speed over the year by hour of the typical day (a composite day summary). A composite day summary is made up of composite hours. A composite hour is the mean of the data taken during a particular hour of the day for all days of the defined time interval. A composite day defines the minimum, maximum, and mean values for 24 composite hours of the defined time interval. The minimum and maximum points are the individual hourly averages which are greater than or less than all other hourly averages.

There is a tendency for wind velocities to be lowest about dawn, at which time there is little vertical thermal mixing and the lower surface air does not couple with the more freely moving upper air. Conversely, velocities of local winds are greatest during the afternoon when the air near the surface exhibits its greatest tendency to move vertically due to terrestrial heating and couples with the faster air moving above it. The larger diurnal variation in wind speed at Sites 3 and 4 can be attributed to the intensity of the stable air masses which result from drainage flows at these sites.

a. Comparison of Wind Speeds Between Sites - The wind speeds at the

Table 3-6-11

MINIMUM, MEAN, AND MAXIMUM SUMMARY FOR WIND SPEED AT SITES 1, 2, 3, AND 4, RBOSP WIND SPEED* (MPH)

TIME PERIOD		SITE 1, 10m Level			SITE 1, 60m Level			SITE 2, 10m Level			SITE 3, 10m Level			SITE 4, 10m Level		
MONTH	YEAR	MINIMUM	MEAN	MAXIMUM	MINIMUM	MEAN	MAXIMUM	MINIMUM	MEAN	MAXIMUM	MINIMUM	MEAN	MAXIMUM	MINIMUM	MEAN	MAXIMUM
FEBRUARY	1975	0.66	7.53	28.68	0.63	10.27	35.76	0.58	9.25	34.51	0.59	6.23	20.71	0.40	5.61	22.24
MARCH	1975	0.66	8.41	29.88	0.53	11.84	43.04	0.63	10.18	30.93	0.70	6.30	19.87	0.00	6.61	26.23
APRIL	1975	0.84	8.94	26.80	0.99	12.86	38.43	0.70	10.71	33.84	0.80	7.23	21.80	0.05	7.17	28.63
MAY	1975	0.56	9.00	30.82	0.55	12.20	40.39	0.57	10.48	31.89	0.06	7.52	20.65	0.06	7.21	25.84
JUNE	1975	1.11	8.86	25.23	0.80	12.12	32.44	1.14	10.15	35.50	0.96	7.67	29.90	0.59	7.00	26.40
JULY	1975	0.80	6.17	18.95	0.56	8.02	25.45	0.62	7.01	22.15	1.22	6.12	17.32	0.72	5.21	19.46
AUGUST	1975	0.70	7.60	30.79	0.58	10.06	41.05	0.86	9.71	36.70	1.02	7.36	23.52	0.65	6.22	31.23
SEPTEMBER	1975	0.68	7.42	22.13	0.57	9.42	28.10	0.61	7.81	26.11	0.58	6.63	21.03	0.54	5.37	21.95
OCTOBER	1975	0.59	8.44	28.53	0.56	12.29	40.64	0.10	9.76	30.64	0.59	7.29	22.30	0.54	6.46	27.30
NOVEMBER	1975	0.68	7.35	27.78	0.69	10.23	39.19	0.50	8.38	34.85	0.89	6.37	22.05	0.54	5.42	29.56
DECEMBER	1975	0.62	5.73	26.93	0.57	7.92	33.06	0.56	6.11	31.77	0.54	5.14	21.46	0.50	4.16	17.08
JANUARY	1976	0.59	6.65	23.87	0.57	9.02	30.29	0.59	7.67	27.81	0.53	5.40	17.39	0.54	4.21	18.07
SEASONAL																
WINTER (February)		0.66	7.53	28.68	0.63	10.26	35.76	0.58	9.28	34.51	0.59	6.23	20.71	0.40	5.59	22.24
SPRING (March, April and May)		0.56	8.74	30.82	0.53	12.22	43.04	0.57	10.45	33.84	0.06	6.98	21.80	0.00	6.96	28.63
SUMMER (June, July and August)		0.70	7.58	30.79	0.56	10.19	41.05	0.62	9.06	36.70	0.96	7.10	29.90	0.59	6.20	31.23
FALL (September, October and November)		0.59	7.76	28.53	0.56	10.68	40.64	0.10	8.63	34.85	0.58	6.73	22.30	0.54	5.76	29.56
WINTER (December, Janruary)		0.59	6.33	26.93	0.57	8.60	33.06	0.56	7.15	31.77	0.53	5.27	21.46	0.50	4.28	18.07
ANNUAL		0.56	7.72	30.82	0.53	10.59	43.04	0.10	9.08	36.70	0.06	6.61	29.90	0.00	5.92	31.23

* Wind Speeds are Hourly Averages

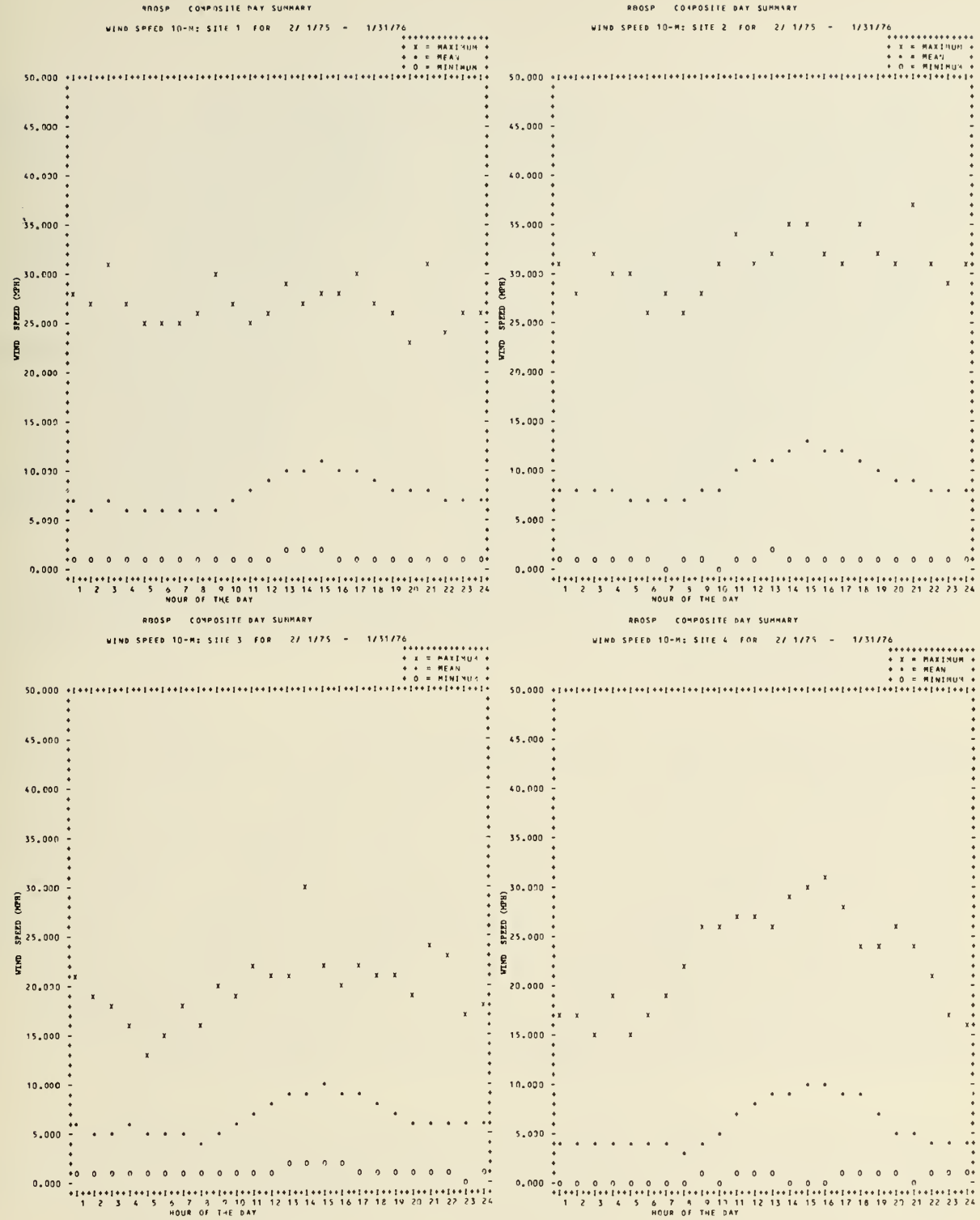


Table 3-6-10

ANNUAL (FEBRUARY 1975 THROUGH JANUARY 1976) WIND SPEED DIURNAL VARIATION (MINIMUM, MAXIMUM AND MEAN) BY HOUR OF DAY FOR 10-METER LEVEL AT SITES 1, 2, 3, AND 4, RBOSP WIND SPEED (MPH)

four sites were analyzed and compared by using scatter diagrams (Figure 3-6-11). These diagrams show the correlation of the frequency of occurrence of values between sites. Display of a multiple joint occurrence is facilitated by plotting an alphabetic character the numeric rank of which, then, indicates the number of joint occurrences, i.e., A equal to one and Z equal to twenty-six. Numbers in excess of 26 are represented by an asterisk. For clarity of presentation, the values of all parameters were quantized into 50 intervals. Because of this quantization, it is common to have more than one joint occurrence in an interval. In addition, the average value of the ordinate is presented as a dash for each abscissa interval. In the scatter diagrams these averages are connected and enhanced with a bold line. Linear coefficients of determination (r^2) were also calculated. The linear coefficient of determination is a statistical indicator of the goodness of fit between two variables, the closer r^2 is to one the more perfect the linear interrelation between the two variables.

Diagram A of Figure 3-6-11 plots wind speeds at Site 2 versus those at Site 1 for the same hour (both measured at 10 m above the local surfact). Only about 68% ($r^2 = 0.68$) of the variation about the mean can be explained by a linear correlation. In other words, 68% of the variation in the wind speed at Site 2 can be explained by the variation of the wind speed at Site 1, assuming a linear relationship. The relatively large variation in the average curve for wind speeds in excess of 20 mph is due to the reduced number of occurrences of these higher values. With fewer numbers of measurements for the average calculation, the standard error of the mean increases.

In contrast with the Site 1 versus Site 2 (ridge site versus ridge site) comparison, the correlation between wind speeds measured at Site 1 and Site 3 (ridge site versus valley site) is not nearly as significant (Diagram B Figure 3-6-11). Here only about 34% ($r^2 = 0.34$) of the variation about the mean can be explained by a linear relationship. In addition, the well-defined boundary to the upper left of the distribution and a poorly-defined boundary to the lower right suggest that high winds at the



Figure 3-6-11

CORRELATION OF WIND SPEED BETWEEN SITES 1, 2, 3, AND 4, RBOSP

valley sites are associated with high winds at the ridge sites. However, high winds at the ridge sites are not necessarily associated with high winds within the valley. A similar distribution is illustrated in Diagram C Figure 3-6-11 in which wind speeds at Site 1 are plotted against those at Site 4. The linear coefficient of determination for this case is only slightly higher (r^2 = 0.43) than that for Sites 1 and 3 (r^2 = 0.34). As expected, the relationship between wind speeds at Sites 3 and 4 (both valley sites) and wind speeds between Sites 1 and 2 (both ridge sites), is more strongly correlated than those for the ridge versus valley sites with a linear coefficient of determination of 0.55 (Diagram D Figure 3-6-11).

b. Correlation of Wind Speed With Wind Direction - To investigate the relationship between wind speed and direction over the year, scatter diagrams of wind speed versus wind direction were prepared for each measurement level of Site 1 and each remote site. These diagrams are presented in Figure 3-6-12.

The diagrams for all three levels of Site 1 show a similar pattern. Winds from the easterly quadrant were light and infrequent. Winds from the south through northwest were strong and frequent. The influence of the small knoll to the southwest of Site 1 is seen as a dip in the average wind speed, which is less pronounced at the greater heights of the point of measurement above the surface. Except for this minor topographical effect, the scatter diagrams for the two ridge sites (1 and 2) are quite similar. Channeling effects and drainage winds complicate the scatter diagrams for the valley sites (3 and 4). Even with this added complexity, the high frequency of low wind speed for down-valley winds at Site 4 is similar to that at Site 3.

c. Wind Persistence - Ambient concentrations of a pollutant will usually be greater at a given downwind point if the wind blows in that direction continuously (e.g., four hours) than if the wind direction is random with time but for four discontinuous hourly intervals blows predominantly in that direction. A time series of meteorological conditions, unusually long lasting, is referred to as a persistence and suggests bias

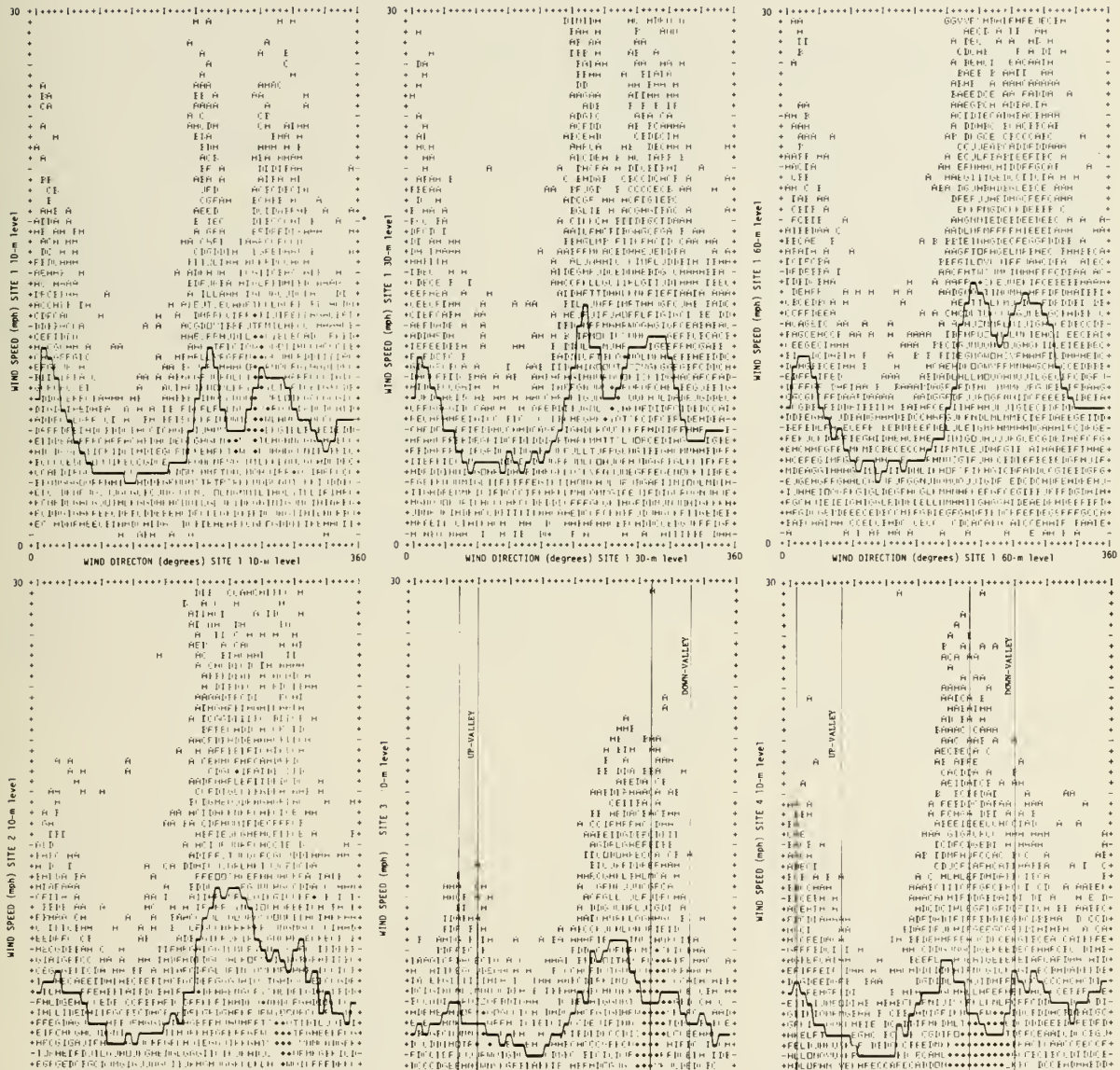


Figure 3-6-12

CORRELATION OF WIND SPEED AND DIRECTION AS MEASURED AT THE SAME LEVEL OF SITES 1, 2, 3 AND 4, RBOSP

away from randomness. Because this effect is significant in any diffusion analysis, persistence of wind direction in the Tract C-a area has been examined.

The wind persistence was calculated by reviewing the wind direction hourly averages sequentially and determining the length of time any particular series of directions fell within a 22½ degree sector--the sequential series being centered on any direction, not merely the 16 compass points. The mean direction of each persistent series of direction data was then calculated in degrees and assigned to a compass point. The wind persistence within any 22½ degree sector is shown in Figure 3-6-13. For example, the graph shows when persistent winds occur at Site 3 there is a 10% chance that they will persist for 4 hr. The number of occurrences of wind-direction persistence is presented as a function of duration and compass point for each of the four sites in Table 3-6-12.

It can be seen from Figure 3-6-13 that the wind direction persistence is greater at Sites 3 and 4 (valley sites) than at Sites 1 and 2 (ridge sites) for intervals up to 12 hours. This is due to wind channeling and to drainage winds in these valleys each night. Once a drainage wind forms, it normally persists throughout the nighttime hours.

In Table 3-6-12 data are tabulated that supplement those presented in the annual wind rose plots (Figure 3-6-9) and give additional insight into the relationships between meteorological conditions and site topography. The sum of wind persistence occurrences in any direction, when converted to percentage, is the wind direction frequency shown in the annual wind rose. The table shows that the majority of wind-direction persistence occurrences do not exceed 8 hours duration and one persistence of 47 hours duration was observed. At Site 1, winds from the south through west-northwest plus winds from the north-northeast are persistent more frequently. Persistences from these directions last longer than those from other directions. At Site 2, persistent winds are generally from the south-southwest through the west-southwest. Infrequent longer persistences occur from the north. The Site 4 persistences reflect the channeling effects and drainage winds of Yellow Creek.

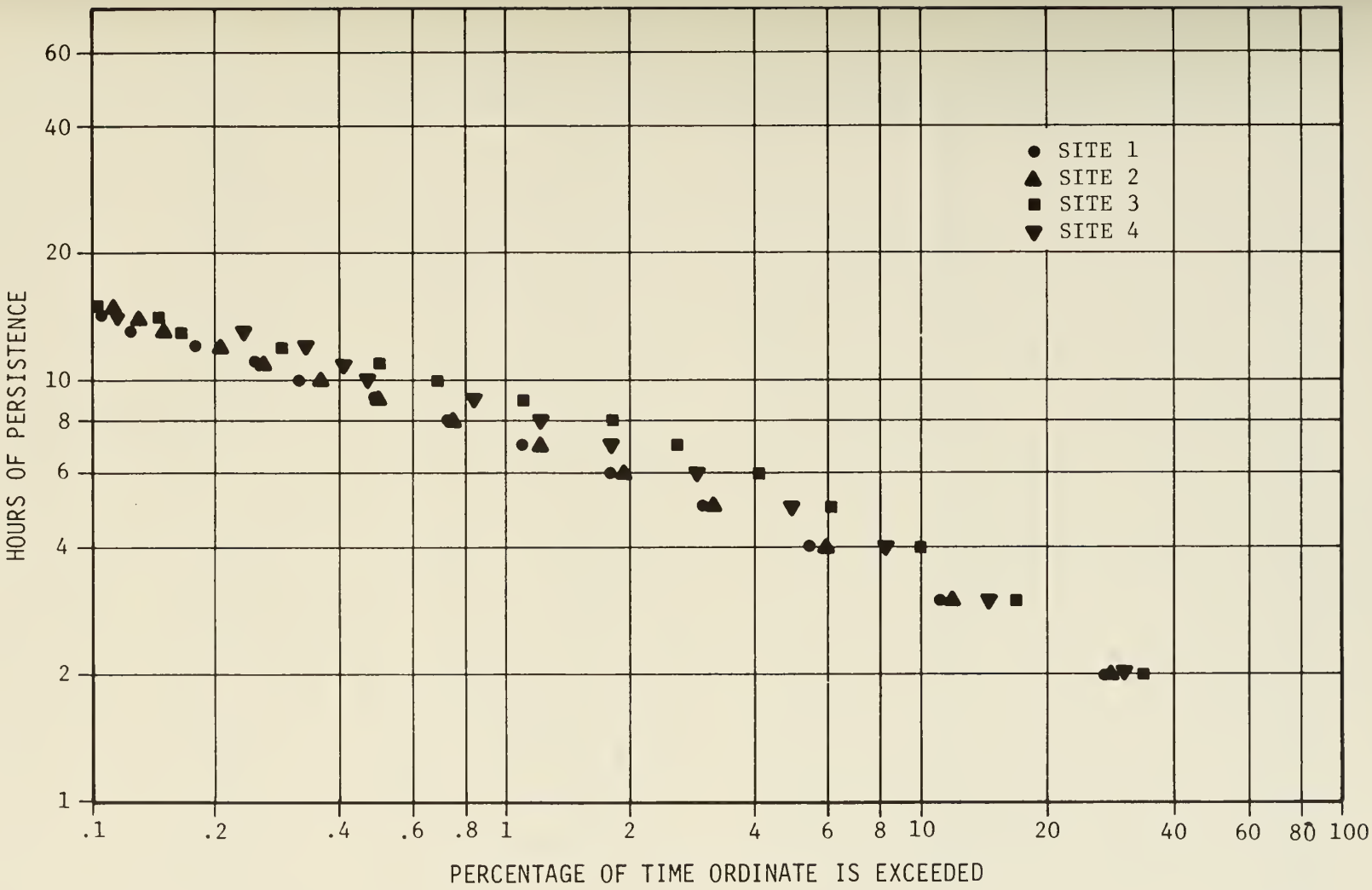


Figure 3-6-13

WIND DIRECTION PERSISTENCES IN ANY 22½ DEGREE SECTOR FOR THE 10-METER LEVEL OF SITES 1, 2, 3, AND 4 (FEBRUARY 1975 THROUGH JANUARY 1976) RBOSP

Table 3-6-12
NUMBER OF OCCURRENCES OF WIND DIRECTION PERSISTENCES BY DIRECTION

SITE 1

PERSISTENCE DURATION (hr)	WIND DIRECTION															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	135	137	182	200	161	131	111	161	277	389	483	495	431	326	249	210
2	26	30	33	37	17	6	9	25	56	122	109	168	93	105	47	27
3	13	17	11	13	6	1	1	1	21	46	29	63	54	33	10	6
4	6	6	4	6	2		1	1	11	22	12	30	14	19	2	3
5		1		2	2				6	18	4	17	9	7	2	
6		2	1						1	10		13	4	4	3	
7		1	2							5		5	4	4		
8		1								3		7	3			
9	1									4		2	1	1		
10		1								1		1	1			
11		2								2						
12									1	1		1				
13		1														
15										1		1				
17										1						
18												1	1			
20										1						

SITE 2

PERSISTENCE DURATION (hr)	WIND DIRECTION															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	183	168	144	137	149	156	171	182	249	333	372	412	430	338	220	157
2	19	30	14	26	21	28	13	31	43	98	130	135	157	88	27	29
3	7	17	5	5	2	7		4	12	43	62	42	65	34	5	4
4	5	10	3	2	1		1	4	2	13	29	27	26	21		1
5		3	2			2			2	11	16	11	12	3	1	1
6		2							1	7	8	6	10	6		
7	1									7	8	1	8	1		
8	1	3								2	2		3	1		
9		1								2	2	1		1		
10		1								1		2	1			
11	1										2					
12											2	1				
13																
15									1							
16										1		1				
17											1					
20										1						
31									1							
47															1	

SITE 3

PERSISTENCE DURATION (hr)	WIND DIRECTION															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	125	77	170	291	320	136	61	52	61	131	278	452	553	270	105	51
2	18	12	31	65	72	15	3	3	8	26	85	124	275	81	14	5
3	2	5	10	32	21	1			1	6	30	44	131	50	2	
4	2	1	6	7	10	1				4	21	18	87	21	1	
5	1		4	1	3						13	8	60	7		
6				1	3					1	7	9	34	14	1	
7			1	1	2					2	1	4	27	2		
8			2							1	2	1	23	5		
9											1	1	17	1		
10			1									1	6	1		
11												1	8	1		
12											1		5			
13													1			
14													2			
15													1			
16												1	2			
20												1				

SITE 4

PERSISTENCE DURATION (hr)	WIND DIRECTION															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	304	234	273	176	107	92	63	130	212	556	524	340	161	113	122	110
2	78	56	61	38	3	5	3	12	49	159	201	89	31	18	12	11
3	35	15	15	17	3		1	5	14	79	104	28	5	5	2	3
4	21	6		6				2	6	38	59	18	3	4		
5	12	7	4	2				1	5	18	36	15	2			1
6		1	1	1					5	14	13	9				1
7	8	1							1	1	17	3				1
8	2									6	9	3				
9	4	1								5	7	2				
10										1	1	1				
11	1									1	2					
12	2									1	1	1				
13	1	1								1	2	1				
14	1											1				
15											1					
16	1															
17	2															

2. Temperature - The valley sites (Sites 3 and 4) have a much larger diurnal temperature variation than the plateau sites (Sites 1 and 2) (Figures 3-6-14 through 3-6-18). The intensity of the cold portion of the composite days at Sites 3 and 4 is much greater than that at Sites 1 and 2. This is due to the cold drainage winds previously discussed. The composite-day air temperature data for Sites 3 and 4 indicate that the early morning temperatures are lower at Site 4 than at Site 3. The 200 ft elevation difference and the stronger drainage winds in Yellow Creek Gulch contribute to this intensity difference. Measurements of horizontal temperature gradients in the presence of surface inversions have indicated that there is very little horizontal change in the inversion rate (Section 3 Chapter 6.2, Upper Air Studies). Therefore, with a 200 ft difference in site elevation, a lower surface temperature would be expected. Although there is a substantial difference in the diurnal variation among all sites, the mean seasonal temperatures and the mean annual temperatures agree well between sites (Table 3-6-13).

The relationship of same-hour surface temperatures between sites was examined by use of scatter diagrams using the same techniques discussed under wind speed and direction above. The surface-temperature scatter diagrams compare Site 1 with Site 2, Site 1 with Site 3, Site 1 with Site 4, and Site 3 with Site 4 (Figure 3-6-19). As found in the wind speeds comparisons (Figure 3-6-11) there is better correlation between sites with similar surrounding topography. Sites 1 and 2 (ridge site versus ridge site) have a linear coefficient of determination (r^2) of 0.97. The larger variation in temperatures at Sites 3 and 4 than at Sites 1 and 2 is again apparent, shown by the breadth of the scatter in the diagrams of Site 1 versus Site 3 and Site 1 versus Site 4. In addition, these diagrams between ridge and valley sites suggest a departure from straight line correlation for very high and very low temperatures. That is, when the temperatures are very high, the valley sites are warmer than the ridge sites, and when the temperatures are very low, the valley sites are colder than the ridge sites. The cold portion may be explained by the frequent valley drainage winds bringing cold dense air over the valley sites. During

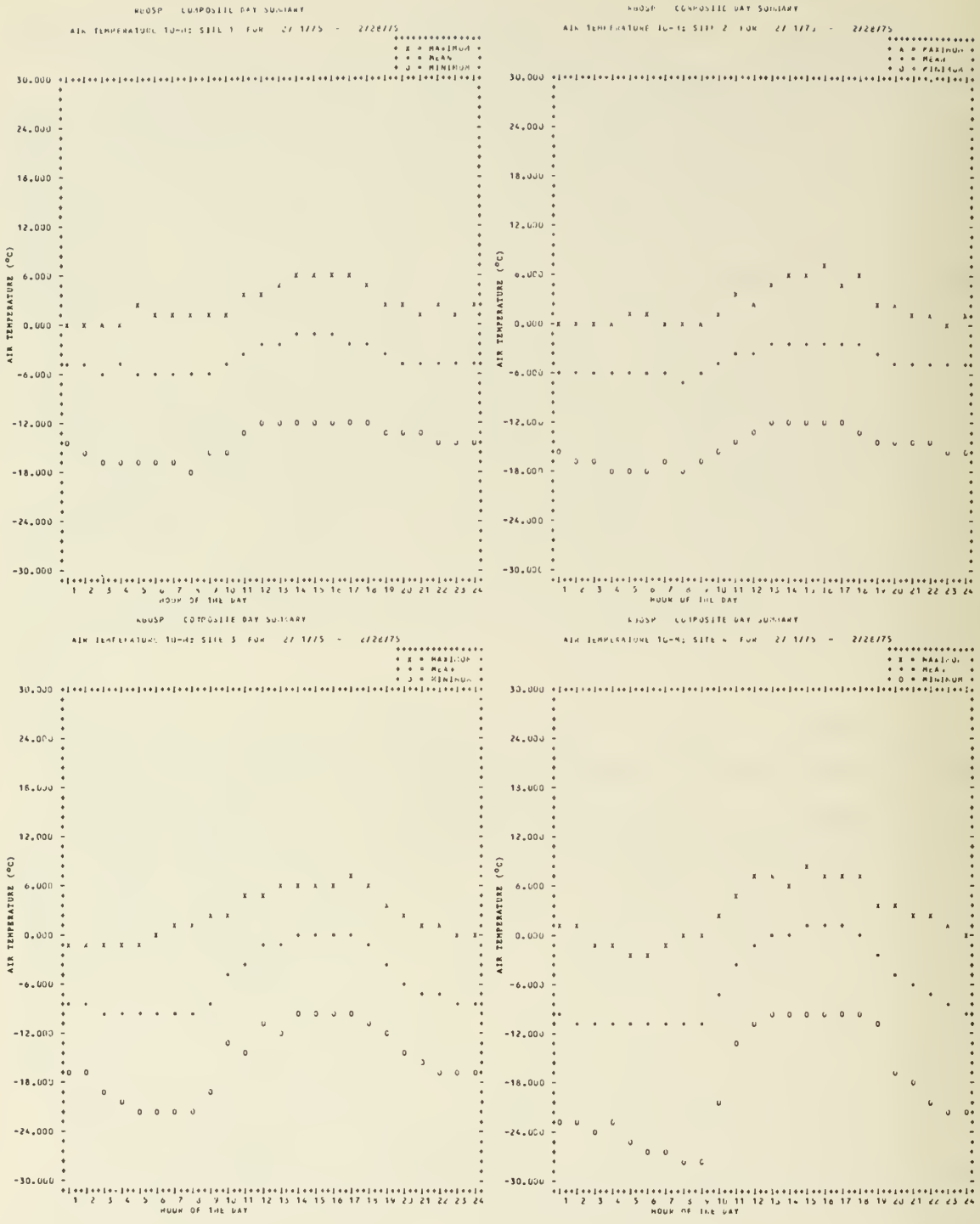


Figure 3-6-14

WINTER 1975 (FEBRUARY) AIR TEMPERATURE (MINIMUM, MAXIMUM AND MEAN BY HOUR OF DAY) FOR THE 10-METER LEVEL AT SITES 1, 2, 3, AND 4, RBOSP AIR TEMPERATURE (°C)

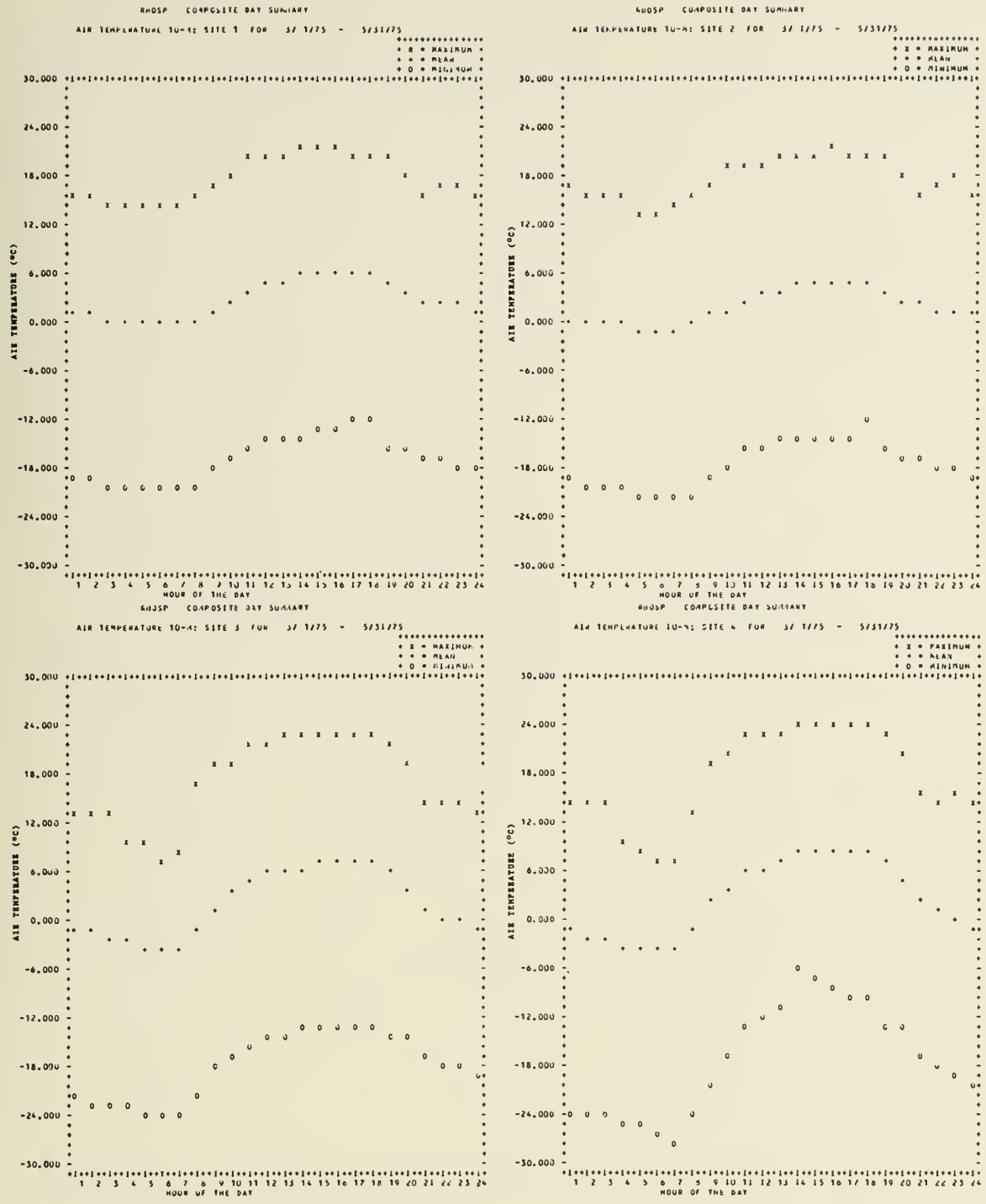


Figure 3-6-15

SPRING 1975 (MARCH, APRIL, MAY) AIR TEMPERATURE (MINIMUM, MAXIMUM, AND MEAN BY HOUR OF DAY) FOR THE 10-METER LEVEL AT SITE 1, 2, 3, AND 4, RBOSP AIR TEMPERATURE (°C)

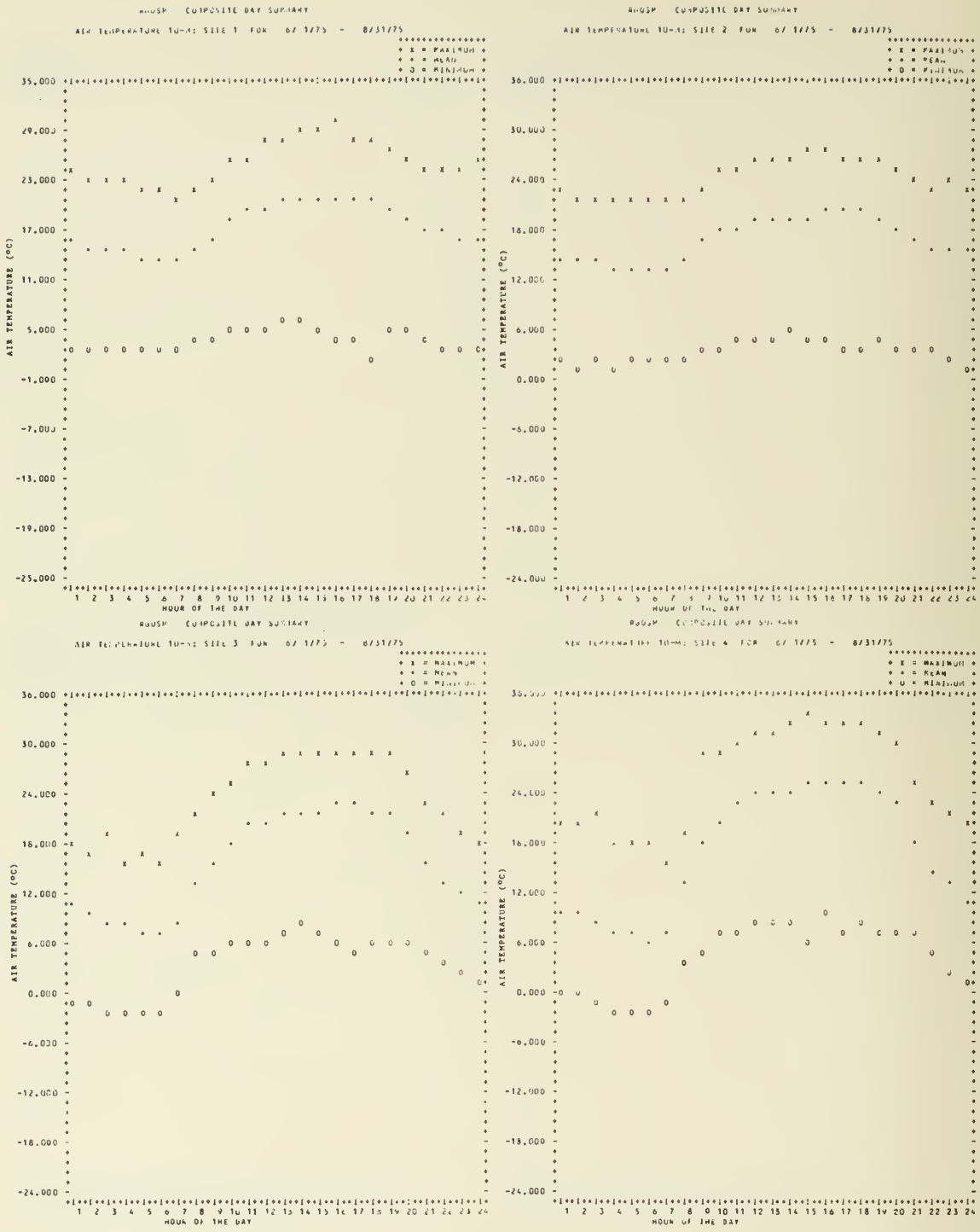


Figure 3-6-16

SUMMER 1975 (JUNE, JULY, AUGUST) AIR TEMPERATURE (MINIMUM, MAXIMUM AND MEAN BY HOUR OF DAY) FOR THE 10-METER LEVEL AT SITES 1, 2, 3, AND 4, RBOSP AIR TEMPERATURE (°C)

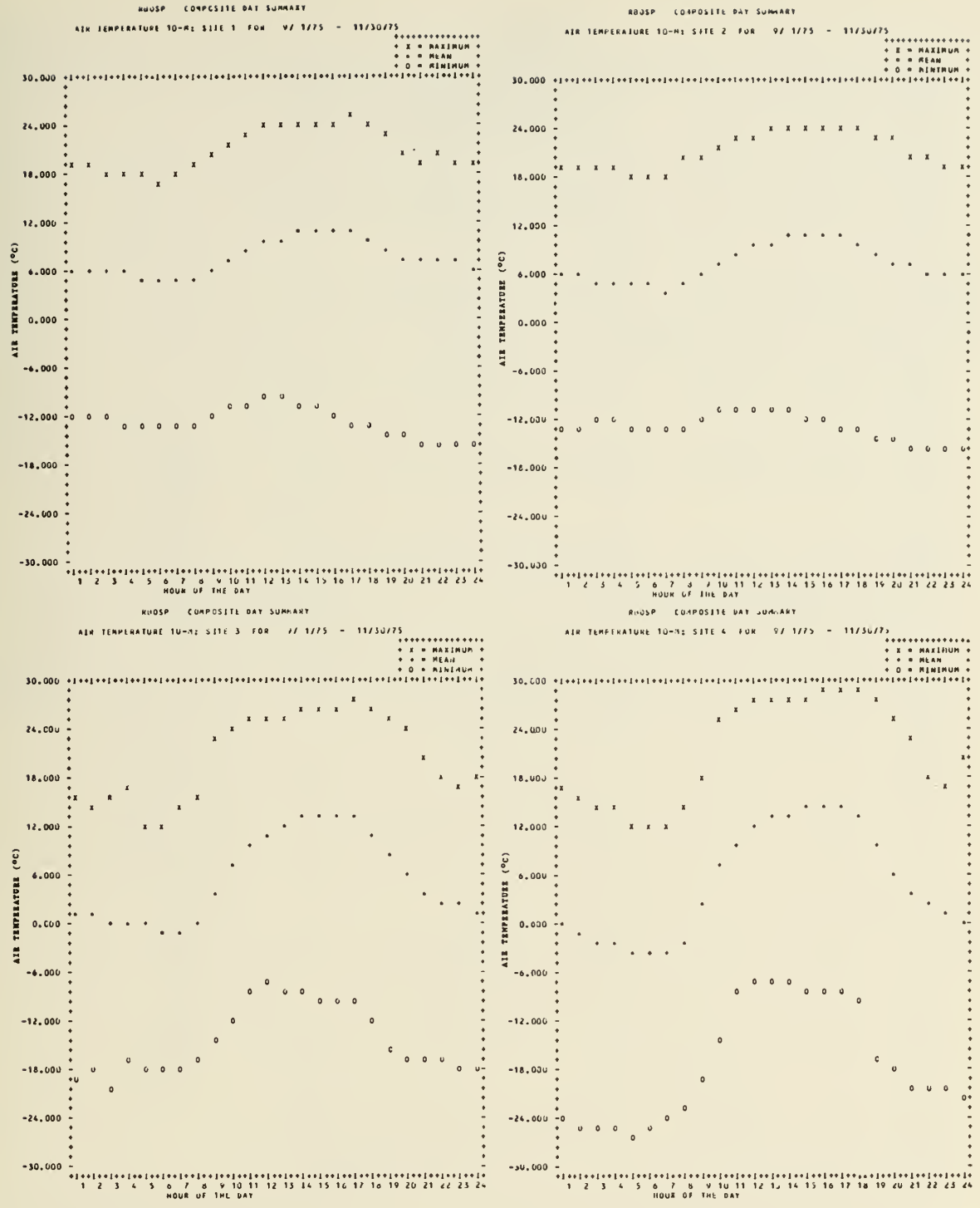


Figure 3-6-17

FALL 1975 (SEPTEMBER, OCTOBER, NOVEMBER) AIR TEMPERATURE (MINIMUM, MAXIMUM, AND MEAN BY HOUR OF DAY) FOR THE 10-METER LEVEL AT SITE 1, 2, 3 AND 4, RBOSP AIR TEMPERATURE (°C)

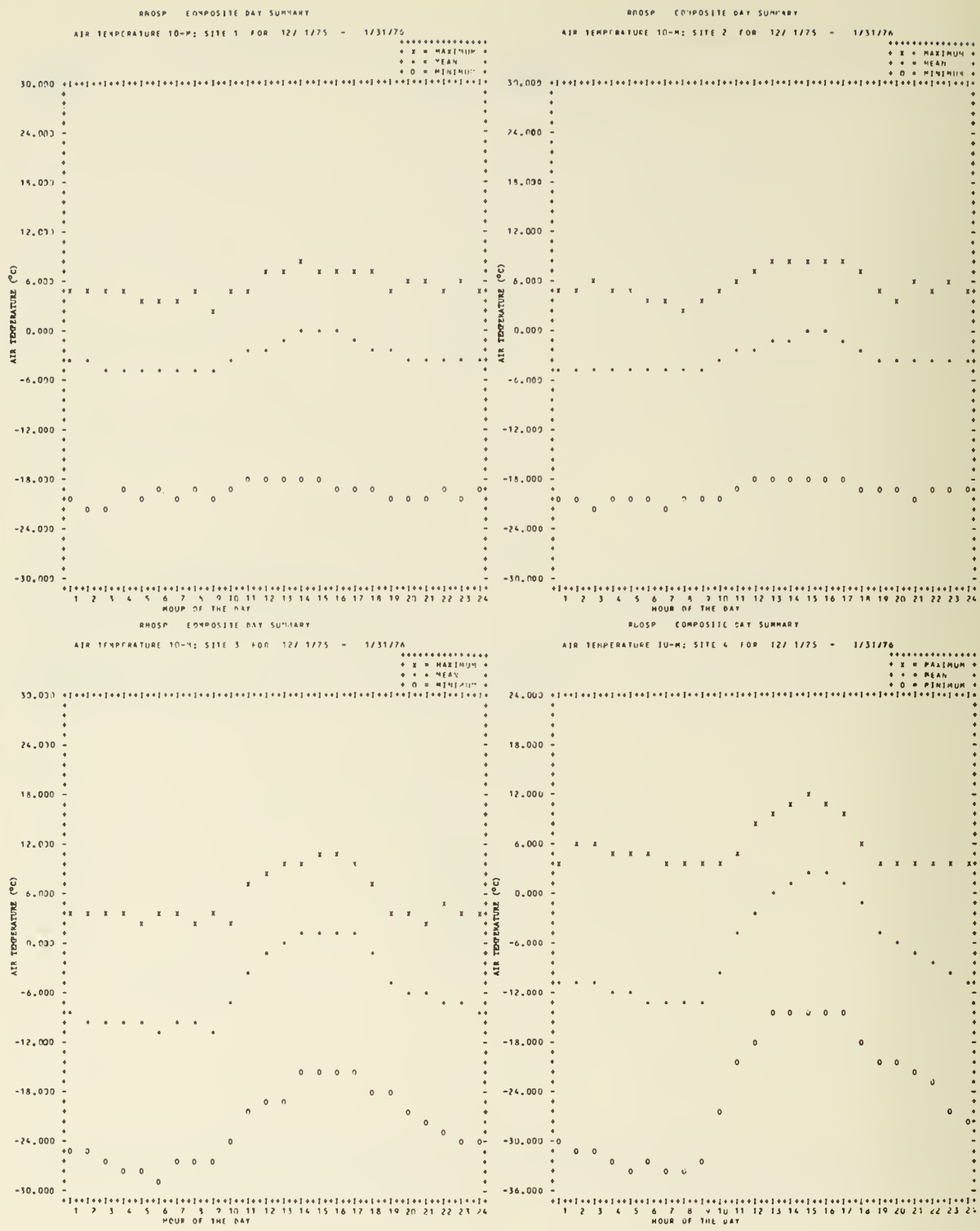


Figure 3-6-18

WINTER 1975-1976 (DECEMBER, JANUARY) AIR TEMPERATURE (MINIMUM, MAXIMUM AND MEAN BY HOUR OF DAY) FOR THE 10-METER LEVEL AT SITES 1, 2, 3, AND 4, RBOSP AIR TEMPERATURE (°C)

Table 3-6-13

MINIMUM, MEAN AND MAXIMUM SUMMARY FOR AIR TEMPERATURE AT 10-METER LEVEL, SITES 1, 2, 3, AND 4, RBOSP AIR TEMPERATURE (°C)

TIME PERIOD		SITE 1			SITE 2			SITE 3			SITE 4		
Month	Year	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum
FEBRUARY	1975	-17.60	-3.86	7.08	-17.80	-4.37	7.27	-21.50	-5.33	8.23	-27.24	-5.88	9.23
MARCH	1975	-20.48	-1.06	9.93	-21.44	-1.81	9.90	-24.35	-1.74	12.09	-27.02	-1.03	13.13
APRIL	1975	-12.10	1.11	14.84	-13.60	0.71	14.64	-21.60	0.61	17.05	-27.00	0.90	18.34
MAY	1975	-3.69	7.95	21.61	-5.47	7.16	21.15	-6.20	7.01	23.11	-9.58	7.21	24.39
JUNE	1975	2.02	13.49	24.51	1.47	13.03	24.46	-2.39	12.07	26.32	-2.97	13.22	29.18
JULY	1975	5.73	19.47	28.24	9.50	19.20	27.47	5.81	17.92	28.97	2.67	19.69	33.14
AUGUST	1975	1.40	18.51	30.07	8.20	18.06	26.97	3.47	16.30	28.76	-0.53	17.37	32.15
SEPTEMBER	1975	2.00	14.41	24.83	2.20	14.02	24.45	-3.40	12.50	27.02	-7.87	11.93	28.35
OCTOBER	1975	-11.40	8.19	20.90	-11.00	7.84	20.88	-15.30	5.75	23.39	-20.30	4.96	24.61
NOVEMBER	1975	-15.80	0.06	15.92	-16.00	-0.14	15.75	-21.00	-1.84	16.20	-25.90	-2.40	16.58
DECEMBER	1975	-14.20	-1.48	8.03	-14.40	-1.78	8.39	-19.60	-4.37	10.24	-23.30	-5.61	11.44
JANUARY	1976	-21.10	-4.44	6.84	-21.30	-4.58	8.57	-28.20	-6.75	9.22	-33.30	-8.20	9.75
SEASONAL													
Winter (February)		-17.60	-3.86	7.08	-17.80	-4.37	7.27	-21.50	-5.33	8.23	-27.24	-5.83	9.23
Spring (March, April, May)		-20.48	-1.06	9.93	-21.44	-1.81	9.90	24.35	-1.74	12.09	-27.02	-1.03	13.13
Summer (June, July, August)		1.40	17.29	30.07	1.47	16.86	27.47	-2.39	15.50	28.97	-2.97	16.82	33.14
Fall (September, October, November)		-15.80	7.50	24.83	-16.00	7.20	24.45	-21.00	5.46	27.02	-25.90	4.85	28.35
Winter (December, January)		-21.10	-3.09	8.03	-21.40	-3.31	8.51	-28.20	-5.62	10.24	-33.30	-6.92	11.44
ANNUAL		-21.10	6.08	30.07	-21.44	5.52	27.47	-28.20	4.33	28.97	-33.30	4.39	33.14

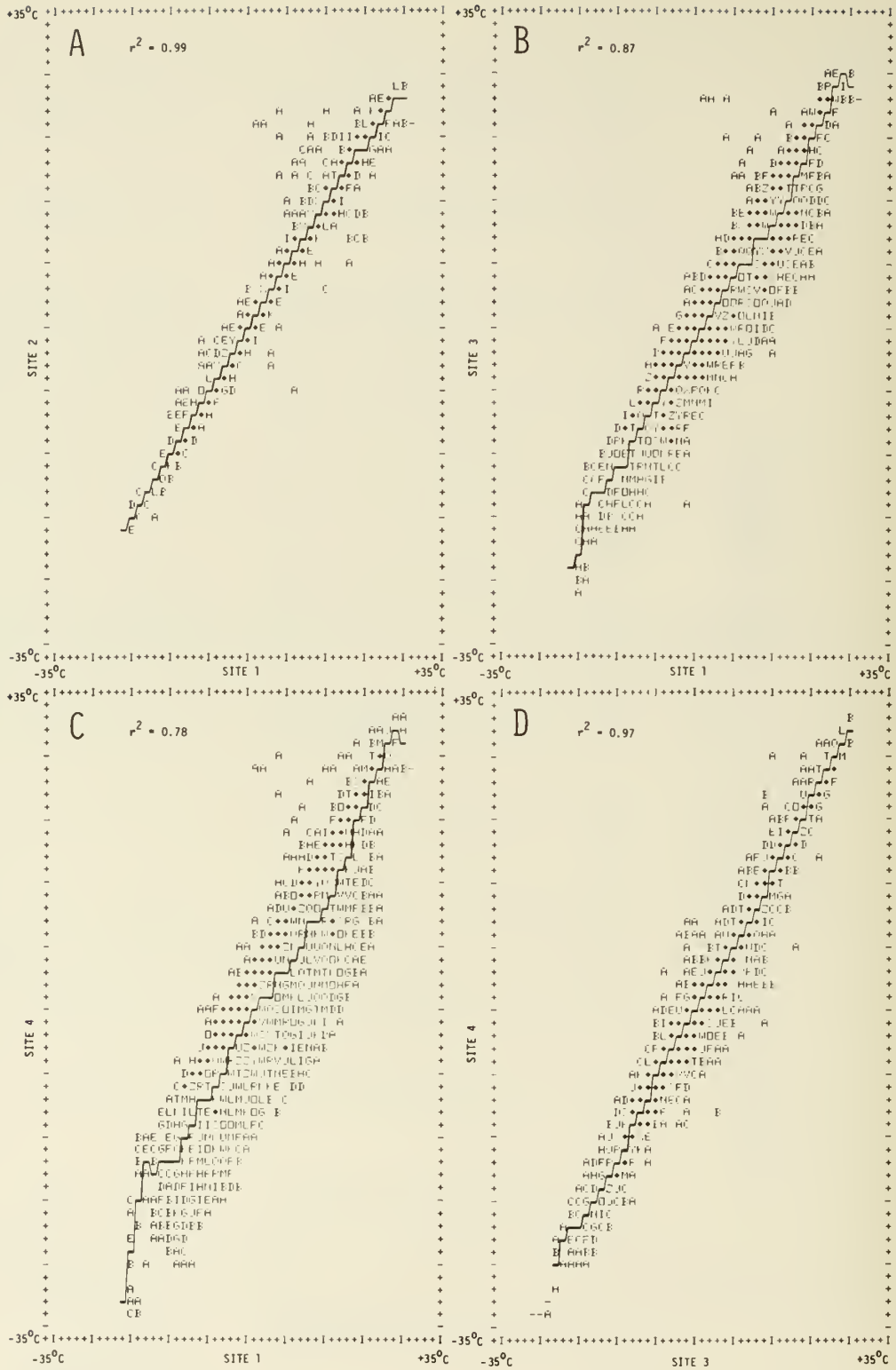


Figure 3-6-19

CORRELATIONS OF AIR TEMPERATURE BETWEEN SITES, RBOSP

the warm hours of day in summer, the air over the area exhibits the typical temperature decrease with height (see atmospheric stability section below). Because the valley sites are at a lower absolute elevation than the ridge sites (about 500 ft), the temperatures within the valleys are significantly warmer than those on the ridge.

The scatter observed in the upper left of Diagrams A, B, and C of Figure 3-6-19, showing the temperature at Site 1 cooler than that at the other three sites, is associated with thunderstorms which formed over Cathedral Bluffs to the west of the Tract C-a and produced precipitation over Site 1 but which dissipated before reaching any of the other monitoring sites.

3. Atmospheric Stability - Emissions of gaseous pollutants are dispersed and diluted by the atmosphere. Wind speed causes dilution of the emissions even at the source. Gross wind direction changes disperse the emisssions over a greater area where they can be diluted by other mechanisms. Wind turbulence and buoyancy enhance the rate at which the emissions are diluted by the atmosphere and thereby reduce ambient pollutant concentrations. Wind speed and wind direction have been discussed previously in this chapter. The mechanisms of turbulence and buoyance and their indicators are discussed below.

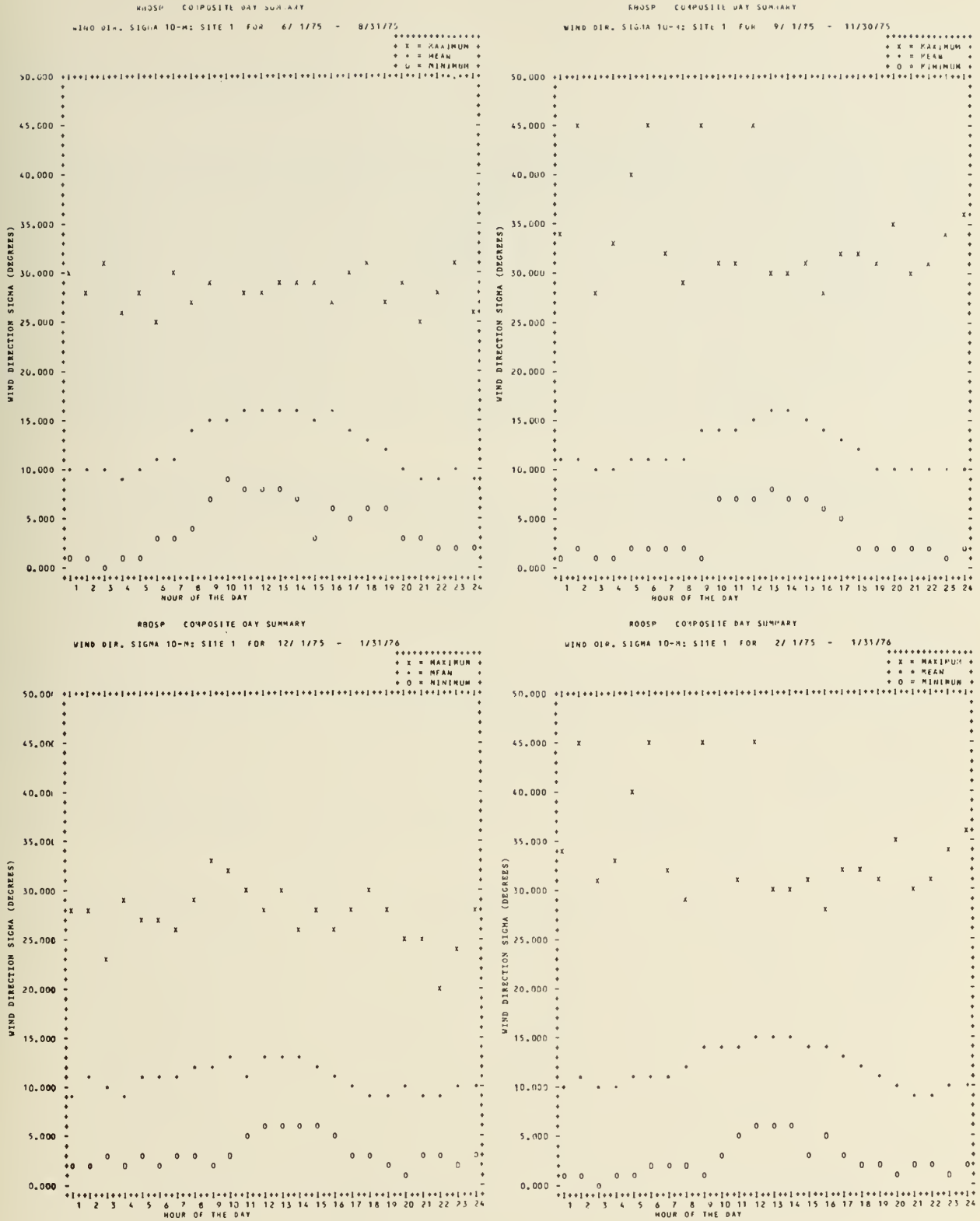
Turbulence is a major factor in diluting emitted concentrations. Turbulence is generated by wind shear in the gradient wind, by surface structures or rough topography, and by atmospheric instability. Turbulence is readily measured by the spectra (frequency and magnitude) of wind direction changes. Although turbulence is three-dimensional, the greater changes are in the horizontal wind direction fluctuations. Horizontal wind direction fluctuations are measured at Tract C-a using the wind direction sensor at the 10-m level at Site 1. The spectra of fluctuations are generally random (Gaussian) and the measurement is the standard deviation expressed as wind sigma as calculated by the on-site minicomputer.

Wind sigma was measured at Site 1 at the 10-m level from June 1975 through

January 1976. The maximum, mean and minimum wind sigma by hour of day is presented by season and for the year in Figure 3-6-20. In general, wind sigmas are greater during the mid-day hours, from about three hours after sunrise to about three hours before sunset.

The gravitational pull of the earth on the air results in an atmospheric pressure decrease with altitude. In the absence of any selected heating or cooling of the atmosphere, atmospheric temperature will decrease (lapse) with increasing altitude at a magnitude termed the adiabatic lapse rate. The dry adiabatic lapse rate (absence of water vapor) is 0.98^{o} C per 100 m. As a result of intense heating (insolation) of the surface by the sun, the actual lapse rate within the first hundred meters of the surface may exceed the dry adiabatic lapse rate, the air becoming buoyant. This means that a parcel of air disturbed upward and expanding adiabatically to the lower pressure is lighter than the surrounding air and tends to continue its rise. The magnitude of this buoyance can be observed in the rapid vertical growth of cumulus clouds during summer days. Such an atmosphere is said to be unstable. On the contrary, during clear nights, the surface may radiate heat to space and create a lapse rate that is less than the adiabatic lapse rate and may even result in a temperature that increases with height (an inversion). In this case, the distrubed air parcel is heavier than the surrounding air and returns toward the surface. This atmosphere is said to be stable. Substances emitted into an unstable atmosphere tend to rise and disperse. Emission released into a stable atmosphere tend to move downwind with little vertical dispersion.

At Site 1, the difference between air temperature at the 10-m and at the 60-m levels was measured with sensitive, matched platinum-wire sensors. This difference, called delta temperature (temperature difference), was analyzed by composite hour. The results are presented by season and for the year in Figure 3-6-21. The sign of delta temperature is the same as lapse rate (decreasing temperature with height is positive delta temperature). Because the height difference is 50 m, the lapse rate (^{o}C/100 m) is twice the delta temperature (^{o}C/50 m) value and the dry adiabatic lapse rate corresponds to a



* Wind Sigma Measurements Commenced Summer, 1975

Figure 3-6-20

WIND DIRECTION SIGMA (MINIMUM, MAXIMUM AND MEAN BY HOUR OF DAY) AT SITE 1, RBOSP WIND DIRECTION SIGMA (DEGREES)

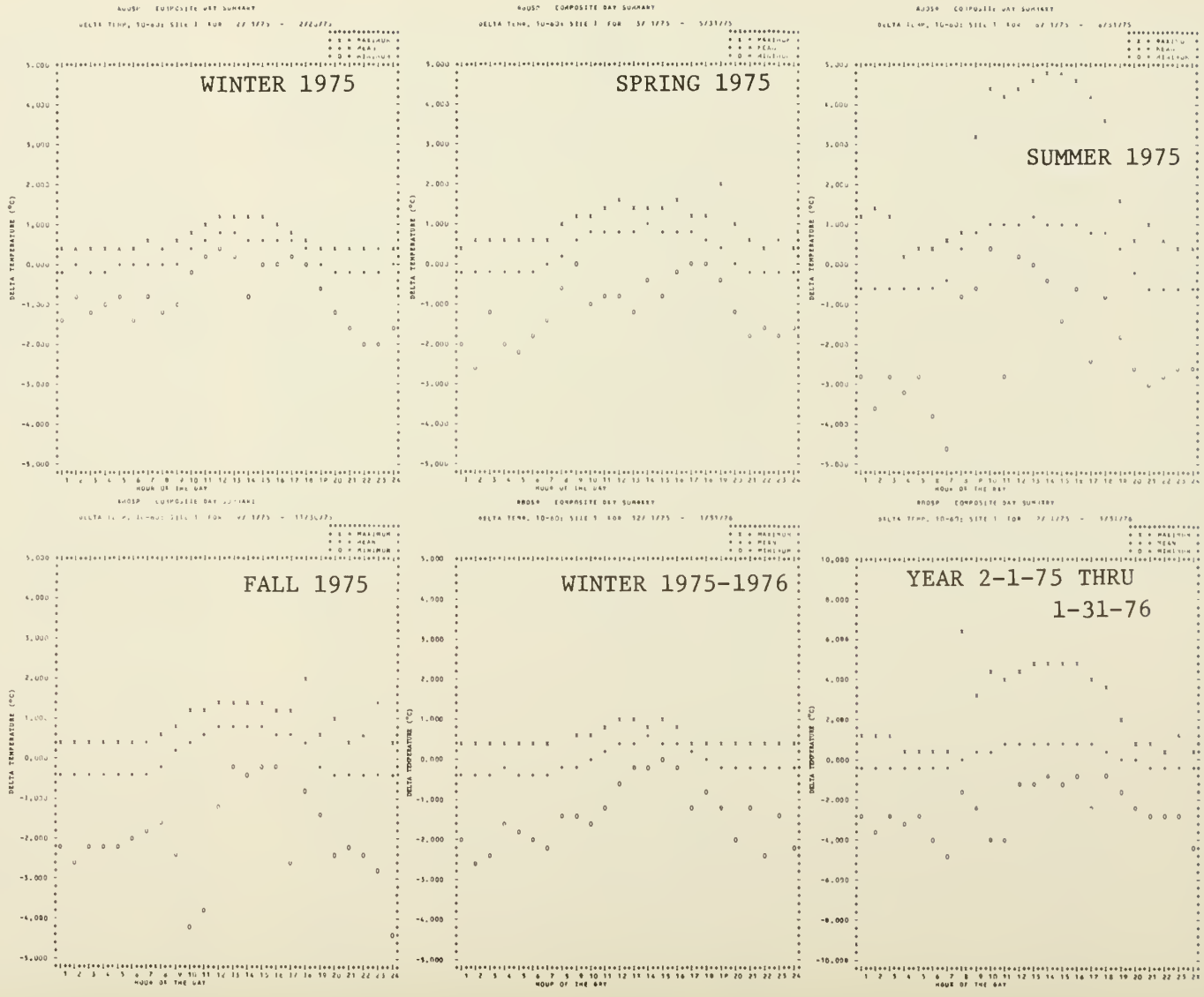


Figure 3-6-21

DELTA TEMPERATURE ($\Delta^{o}C$) BETWEEN 10 AND 60-METER LEVELS
(MINIMUM, MAXIMUM AND MEAN BY HOUR OF DAY) AT SITE 1, RBOSP

delta temperature of 0.49°C.

In general, the delta temperature data indicate stability at night and instability during the middle of the day (Figure 3-6-21). The minimum delta temperatures (most stable conditions) were greater than the maximum delta temperatures (most unstable conditions). The break-up of the usual surface inversion (as indicated by an unstable value of the mean composite-day delta temperature) generally occurred within an hour of sunrise. Analysis by season shows that the mean nocturnal inversion during winter and fall was significantly more intense than that during spring and summer.

In analyzing the diffusion characteristics of the atmosphere with meteorological data, Pasquill (Slade, 1968) discovered that categorization of effluent dispersion resulted in lapse rate and wind sigma also being grouped into well-defined classes. These relationships are illustrated in Table 3-6-14.

Mean wind sigma values were categorized according to stability classifications (Slade, 1968; NRC, 1972), grouped by season and annually, and converted to percentage of occurrence; the results are presented in Table 3-6-15. Also included in the table are the average associated wind speeds. Highest wind speeds were associated with the neutral stability category D.

Mean delta temperature values were also categorized according to stability classifications, grouped by season and annually, and converted to percentage of occurrence; the results are presented in Table 3-6-16. Also included in the table are the average associated wind speeds. Highest wind speeds were associated with the more unstable categories rather than the neutral stability category. The high wind speeds which were found to be associated with the extremely stable category G during the summer of 1975 were examined and it was found that these winds almost always came from the southwest through northwest quadrant. These winds have been associated with the movement of warm fronts through the area during the hours of darkness.

Table 3-6-14

CLASSIFICATION OF ATMOSPHERIC STABILITY

Stability Classification	Pasquill Category	Wind Sigma (Degrees)	Temperature gradient with height (°C/100m) (Negative lapse rate)	Delta Temperature (°C/50m)
Extremely unstable	A	greater than 22.5	less than -1.9	greater than 0.95
Moderately unstable	B	17.5 to 22.5	-1.9 to -1.7	0.95 to 0.85
Slightly unstable	C	12.5 to 17.5	-1.7 to -1.5	0.85 to 0.75
Neutral	D	7.5 to 12.5	-1.5 to -0.5	0.75 to 0.25
Slightly stable	E	3.75 to 7.5	-0.5 to 1.5	0.25 to -0.75
Moderately stable	F	2.10 to 3.75	1.5 to 4.0	-0.75 to -2.00
Extremely stable	G	less than 2.10	greater than 4.0	less than -2.00

Source: Slade, 1968; NRC, 1972

Table 3-6-15

PERCENTAGE OF OCCURRENCE OF STABILITY CLASSES WITH ASSOCIATED WIND SPEEDS USING WIND DIRECTION DEVIATION CATEGORIZATION SCHEME, RBOSP

Period	Percent of Occurrence of Stability Class							
	A	B	C	D	E	F	G	Total %
Winter (February)	*	*	*	*	*	*	*	*
Spring (March, April, May)	*	*	*	*	*	*	*	*
Summer (June, July, August)	5.89	11.09	28.70	29.67	19.55	4.28	0.83	100.00
Fall (September, October, November)	8.31	9.71	23.38	31.23	20.11	6.04	1.23	100.00
Winter (December, January)	5.35	7.61	19.47	31.53	30.23	5.41	0.41	100.00
Annual (February 1975 through January 1976)	6.62	9.66	24.24	30.72	22.62	5.27	0.88	100.00

	Associated Wind Speeds (MPH)							Total Weighted Average
Winter (February)	**	**	**	**	**	**	**	**
Spring (March, April, May)	**	**	**	**	**	**	**	**
Summer (June, July, August)	5.16	5.89	8.05	8.78	6.91	7.59	8.89	7.62
Fall (September, October, November)	7.32	6.36	8.91	8.43	6.76	6.85	7.21	7.80
Winter (December, January)	5.31	4.78	6.52	7.19	5.83	5.70	5.35	6.28
Annual (February 1975 through January 1975)	6.22	5.86	8.03	8.21	6.49	6.78	7.58	7.34

*wind direction deviation (sigma) measurements did not begin until Summer 1975
**not applicable

Table 3-6-16

PERCENTAGE OF OCCURRENCE OF STABILITY CLASSES AND ASSOCIATED WIND SPEEDS USING DELTA TEMPERATURE, RBOSP

Period	Percent of Occurrence of Stability Class							
	A	B	C	D	E	F	G	Total %
Winter (February)	2.74	4.18	6.92	32.42	48.85	4.76	0.14	100
Spring (March, April, May)	11.54	6.19	6.05	30.27	40.26	5.58	0.09	100
Summer (June, July, August)	18.38	6.72	6.11	18.19	35.54	13.20	1.87	100
Fall (September, October, November)	5.36	4.09	5.27	28.43	43.96	11.67	1.23	100
Winter (December, January)	0.21	0.34	1.03	33.52	54.42	10.08	0.41	100
Annual (February 1975 through January 1976)	9.07	4.64	5.07	27.56	43.05	9.73	0.87	100
	Associated Wind Speeds (MPH)							Total Weighted Average
Winter (February)	7.16	6.95	7.68	9.58	6.19	6.09	4.11	7.53
Spring (March, April, May)	9.87	9.28	9.61	9.55	7.39	7.58	5.08	8.59
Summer (June, July, August)	10.26	8.98	8.05	7.84	5.60	7.59	9.09	7.57
Fall (September, October, November)	12.56	10.84	9.29	8.82	6.37	6.77	7.77	7.80
Winter (December, January)	9.23	9.68	8.09	8.80	5.12	3.94	3.57	6.28
Annual (February 1975 through January 1976)	10.41	9.38	8.80	8.94	6.16	6.63	7.71	7.65

Inasmuch as wind sigma, delta temperature, and insolation are related to atmospheric stability, correlations between the variables within stability categories were investigated using the scatter diagram technique. The results of insolation measurements are discussed elsewhere in this chapter. Scatter diagrams for wind sigma with delta temperature, insolation with delta temperature, and insolation with wind sigma are presented in Figure 3-6-22. Stability classes associated with both axes are superimposed on scatter diagram A using the classification scheme defined in Table 3-6-14. For perfect correlation of wind sigma, delta temperature, and stability class (Diagram A Figure 3-6-22) all occurrences would fall within the like stability rectangles indicated. The lack of correspondence lies not with the data but with the classification scheme which was not designed for use in an area with as much topographical influence as found in the Tract C-a area. Because there is a lower frequency of occurrence of stable conditions defined from wind sigma measurements than from the delta temperature measurements, the latter method provides more conservative estimates of effluent dispersion.

The scatter diagrams for insolation (Diagrams B and C Figure 3-6-22) show that delta temperature is much more dependent upon insolation than is wind sigma. This is due to the direct dependence of surface temperature on insolation. The average behavior of wind sigma and solar insolation shows a general increase in insolation with an increase in wind sigma.

The stability parameters, delta temperature and wind sigma, were also correlated with wind speed and wind direction by means of scatter diagrams (Figure 3-6-23). The correlation of delta temperature with wind speed shows a general trend of higher wind speeds being associated with more unstable conditions. This agrees with the data presented in Table 3-6-16. The correlation of delta temperature with wind direction indicates a relative minimum in delta temperature being associated with westerly winds (around 270^{o}). Since the scatter diagram of wind speed with wind direction (Figure 3-6-12) indicates a relative maximum in wind speed from

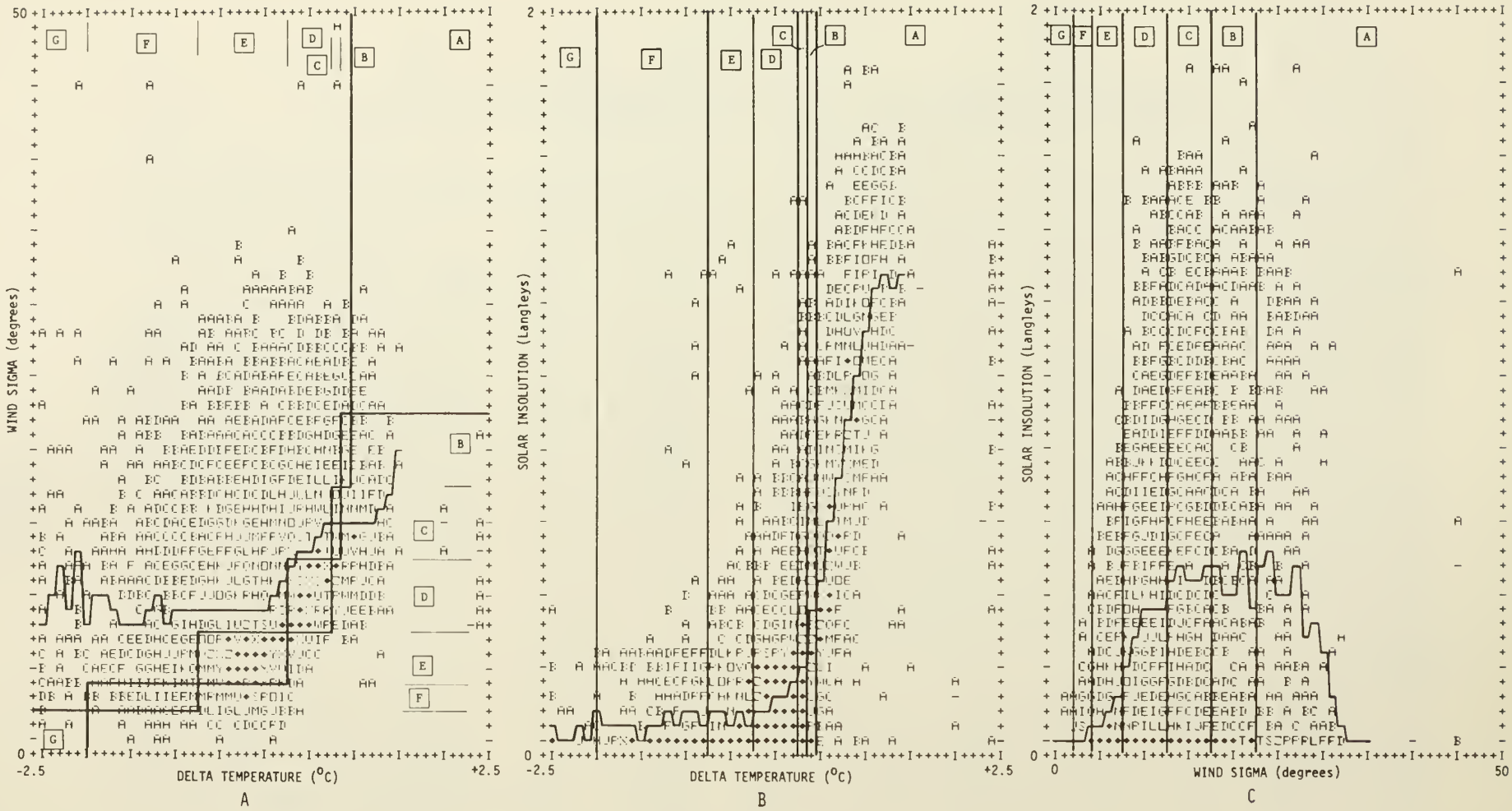


Figure 3-6-22

CORRELATIONS AMONG THE STABILITY PARAMETERS DELTA TEMPERATURE, WIND SIGMA, AND SOLAR INSOLATION MEASURED AT SITE 1, RBOSP

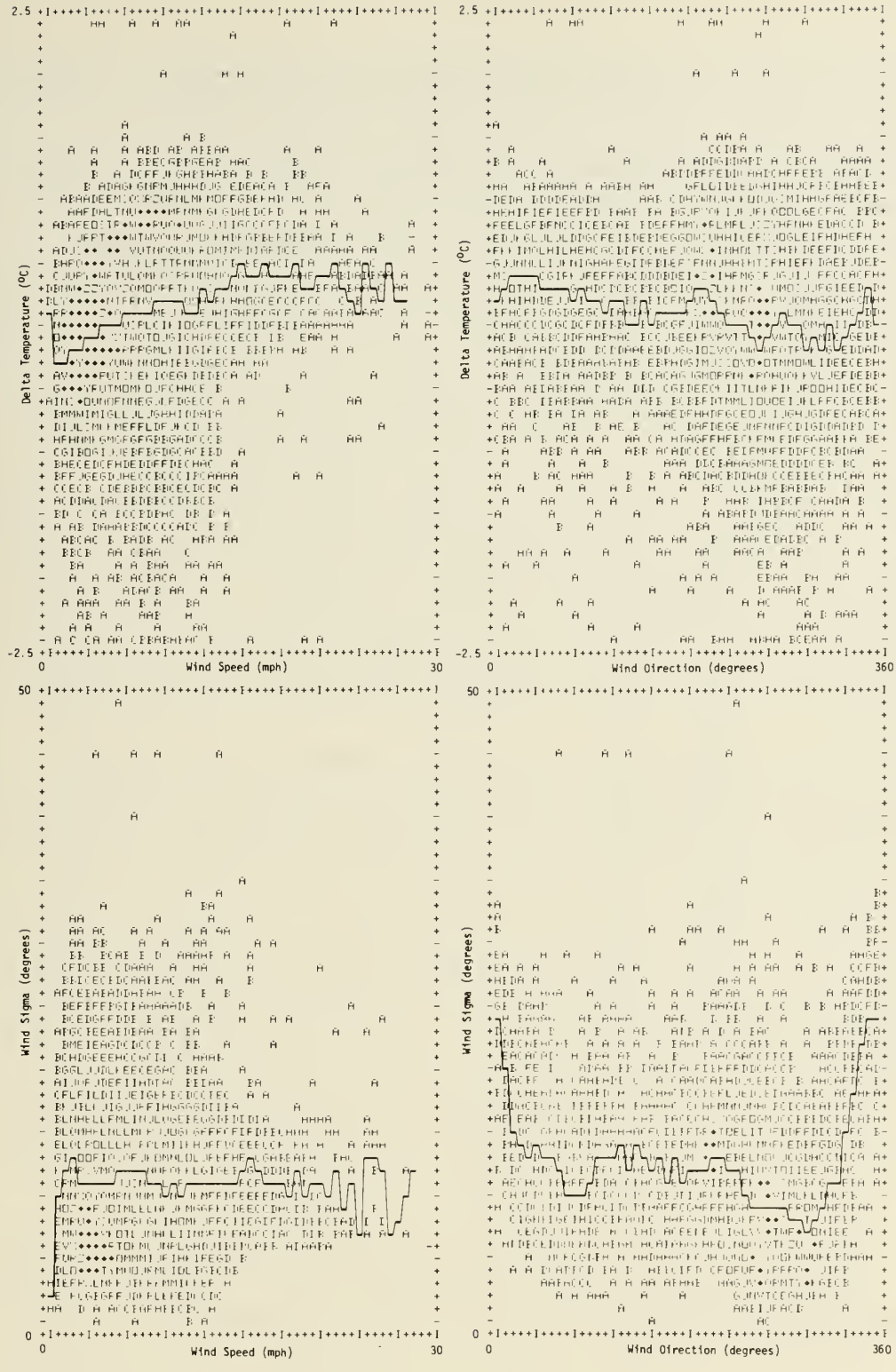


Figure 3-6-23

CORRELATIONS OF DELTA TEMPERATURE AND WIND SIGMA WITH WIND SPEED AND WIND DIRECTION MEASURED AT SITE 1, RBOSP

the westerly direction, it is apparent that westerly winds were synoptically associated with more stable air than winds from other directions. Indeed, the association is large enough to obscure the relationship between high wind speed and high delta temperature. The correlation betwen wind sigma and wind speed shows little interrelationship. Higher wind speeds are associated with a high degree of mechanically induced turbulence. However, lower wind speeds cause the wind vane used for the measurement to meander more; this also produces relatively high measurements of sigma. The net result is a nearly "flat" curve describing the average value of sigma as a function of wind speed. The correlation of wind sigma with wind direction indicates a relative minimum of wind sigma (stable class) for the westerly winds (around 270^{o}) which corroborates the similar conclusion using the correlation of delta temperature with wind direction. The high values of wind sigma for northerly winds are misleading due to the 0-360 degree sensor used and the artificial discontinuity which it introduced about north.

Because of the strong diurnal variation in temperature structure over the tract, inversions (measured by delta temperature) never persisted more than 19 hrs. The normal sequence of events showed a moderately intense surface inversion forming shortly after sunset and breaking up shortly after sunrise (Figure 3-6-21). This behavior is illustrated as persistence of inversions in Figure 3-6-24. For example, this graph shows that there is a 4% chance that if an inversion is present, it will persist for more than 15 hours. The frequency of persistence is high up to 10 hours duration and reflects the length of day as well as the frequency of inversions. The number of occurrences of inversions measured during the period is presented in Table 3-6-17 as a function of wind direction and persistence duration.

4. Relative Humidity - Relative humidity is of importance for biology and hydrology as well as an indicator of soil conditions favorable as a source for fugitive dust.

Relative humidity was measured at the 10-m level at Site 1. The data have been analyzed by composite hour and are presented as diurnal variations of

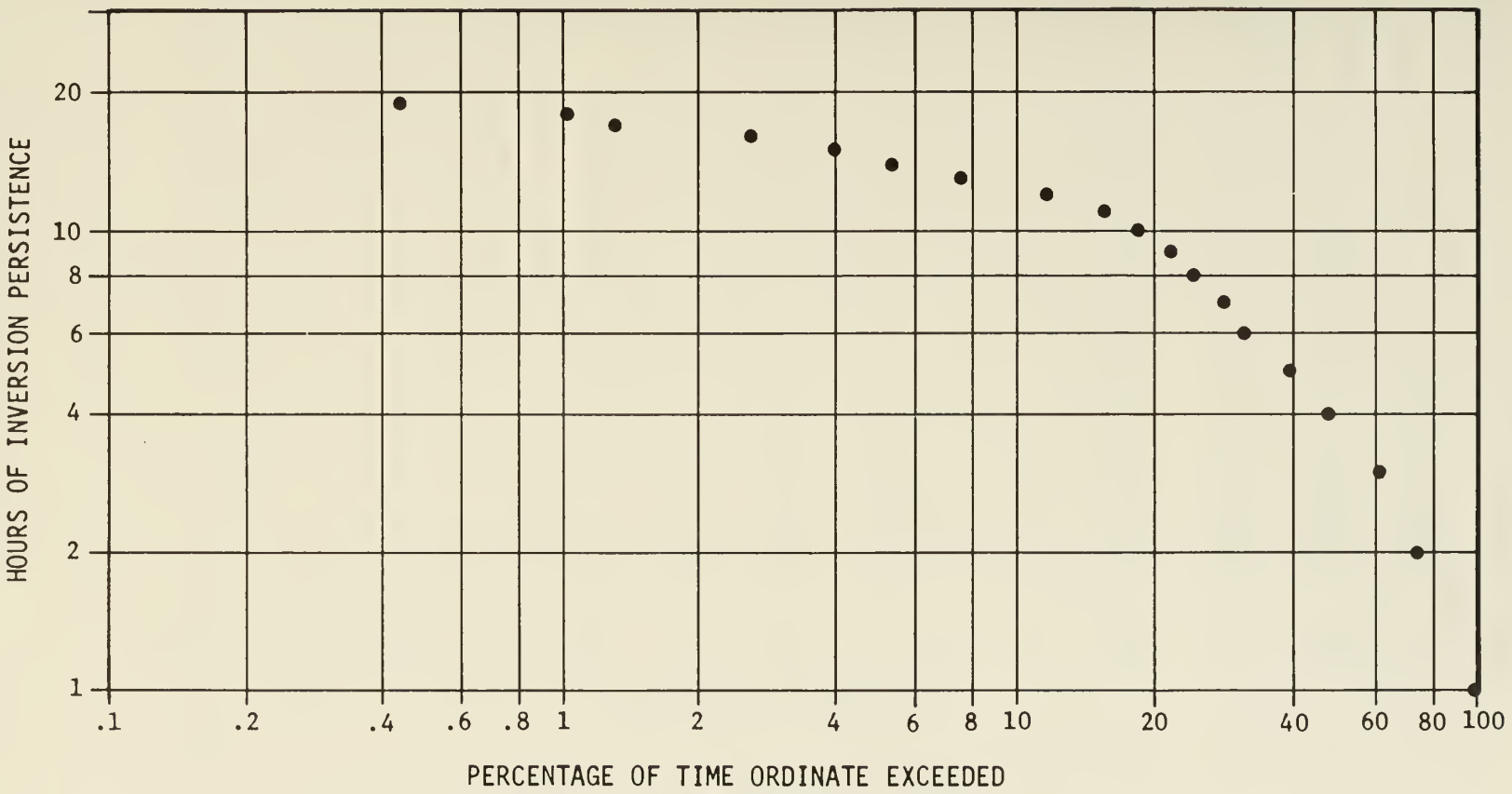


Figure 3-6-24

PROBABILITY OF INVERSION PERSISTENCE GIVEN
AN INVERSION EXISTS, RBOSP

Table 3-6-17

NUMBER OF OCCURRENCES OF INVERSION PERSISTENCES
CATEGORIZED BY WIND DIRECTION, RBOSP

PERSISTENCE DURATION (hr)	WIND DIRECTION															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1	5	2	1	9	4	4	5	8	8	20	12	24	22	25	16	10
2			1	3			1	7	7	14	12	13	12	15	6	2
3	2	1			1			2	6	3	17	18	15	8	9	1
4				1				1	2	7	10	16	6	11	9	1
5	1	1		1			1	1	1	6	7	12	11	7	1	2
6	1								1	3	5	2	3	2	5	1
7										1	4	6	9	2		2
8										1	5	4	4	4	1	1
9									1	2	3	9	3	5	1	
10	1									4	1	7	3	3		1
11										1	3	12	5	4		
12	1									3	4	12	5	2	1	1
13										2	1	8	3		1	
14											1	6	1	1		
15										2		5	2			
16										1	2	5	1			
17										1		1				
18									1			2				1
19											2		1			

maximum, mean and minimum relative humidity by season and for the year in Figure 3-6-25. These data show that the relative humidity decreases during daylight hours. This can partially be explained by the increase in temperature. However, during the spring season the relative humidity decrease exceeds that expected from just air warming and may be associated with the surface winds that increase at approximately the same time as the humidity decreases and which bring drier air from upper levels to the surface.

The relative humidity data have been summarized for month, season, and the year in Table 3-6-18. These data show that mean relative humidity is much less during the warmer months than during the colder months.

The relationships between atmospheric moisture and other atmospheric variables were investigated by use of scatter diagrams. Correlations of relative humidity with wind speed, wind direction, delta temperature, and wind sigma are presented in Figure 3-6-26. There is an indication of decrease in relative humidity with increasing wind speed for wind speeds up to about 10 mph. For wind speeds above 10 mph, there is no apparent dependence of relative humidity on wind speed. The few points related to high relative humidity and high wind speed were associated with thunderstorm activity in the area. On the average, higher relative humidity was associated with northerly winds. In addition, relative humidity was greatest when the atmosphere was nearly isothermal (delta temperature near zero) but dropped markedly as the delta temperature increased or decreased. Relative humidity versus wind sigma is presented in Diagram D Figure 3-6-26. The relationship shows a complex behavior with two relative maximums and minimums. The high values of relative humidity associated with high values of wind sigma may be due to the relationship of high relative humidity with northerly winds shown in Diagram B in conjunction with the artificial values introduced into the wind sigma measurement by the 0-360 degree sensor.



Figure 3-6-25

RELATIVE HUMIDITY AS PERCENT SATURATION (MINIMUM, MAXIMUM AND MEAN BY HOUR OF DAY) AT SITE 1, RBOSP

Table 3-6-18

MINIMUM, MEAN AND MAXIMUM SUMMARY FOR THE RELATIVE HUMIDITY
AT 10 METER LEVEL, SITE 1, RBOSP
RELATIVE HUMIDITY (%)

Month	Year	Minimum	Mean	Maximum
February	1975	16.64	51.73	92.87
March	1975	18.39	52.97	93.12
April	1975	19.66	45.81	91.58
May	1975	16.19	41.47	91.07
June	1975	10.21	31.35	86.72
July	1975	10.14	24.81	84.21
August	1975	10.00	21.32	81.36
September	1975	13.00	26.64	88.07
October	1975	14.52	31.55	91.20
November	1975	15.23	40.89	89.79
December	1975	17.91	29.21	83.41
January	1976	16.34	33.58	89.56
SEASONAL				
Winter (February)		16.64	51.73	92.87
Spring (March, April, May)		16.19	46.75	93.12
Summer (June, July, August)		10.00	25.52	86.72
Fall (September, October, November)		13.00	33.62	91.20
Winter (December, January)		16.34	31.31	89.56
ANNUAL		10.00	35.99	93.12

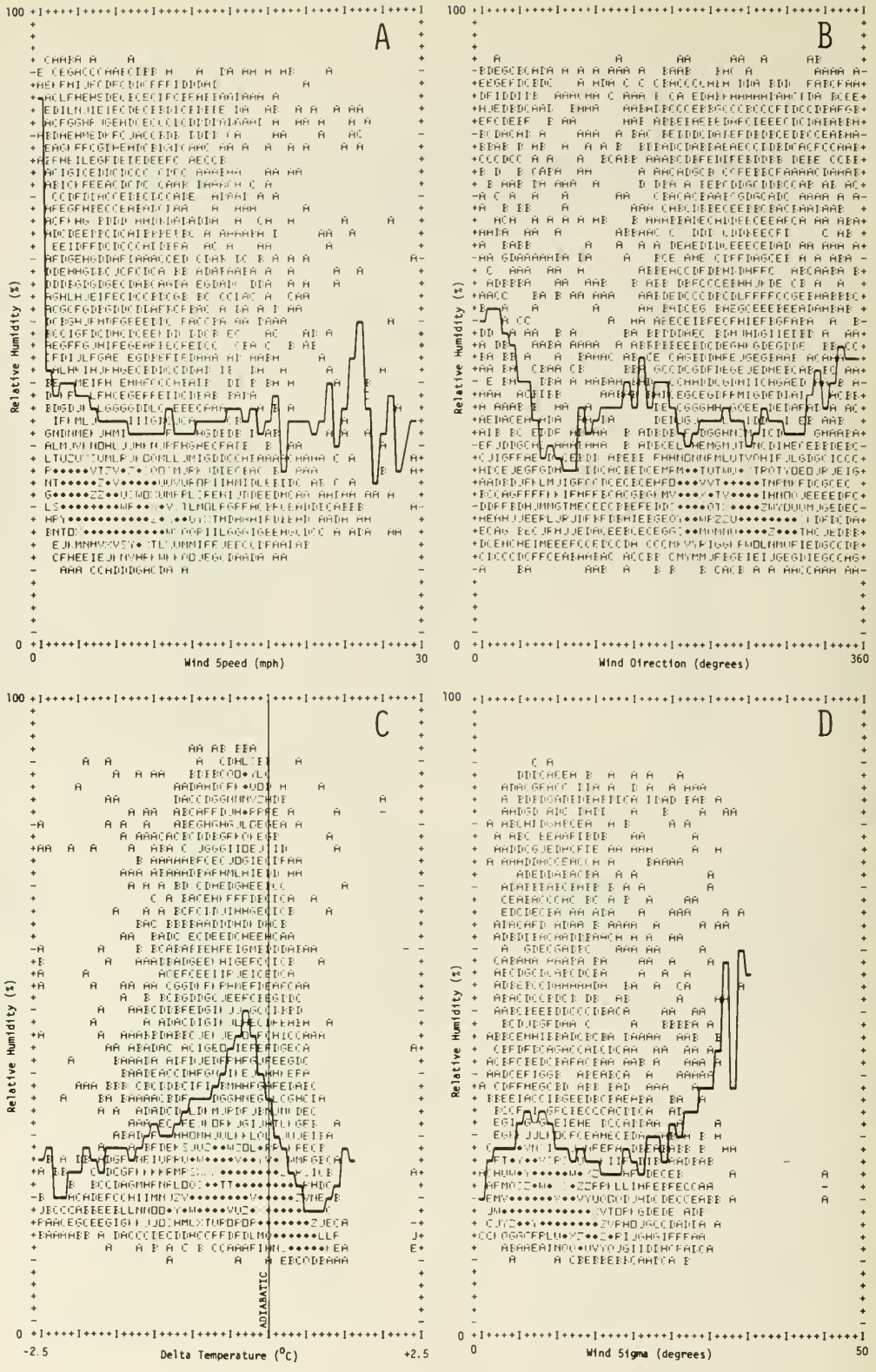


Figure 3-6-26

CORRELATION OF RELATIVE HUMIDITY WITH WIND SPEED, WIND DIRECTION, DELTA TEMPERATURE AND WIND SIGMA, SITE 1, RBOSP

6.2 UPPER AIR STUDIES

The upper air studies program was performed for the Tract C-a Rio Blanco Oil Shale Porject over the course of four intensive 15-day quarterly periods during 1974 and 1975 as follows: fall study, October 1 to 15, 1974; winter study, January 20 to February 9, 1975; spring study, April 14 to May 1, 1975; and summer study, July 12 to 26, 1975. The measured data consisted of ambient temperature soundings from about 6,300 ft to 13,000 ft above MSL with values recorded at 100 ft increments, and wind speed and direction soundings from about 7,000 ft to 13,000 ft above MSL with values calculated at 300 ft increments. Because of safety considerations, some soundings were cancelled due to inclement weather conditions. Although this tends to bias the data towards more stable (conservative) periods, the wide range of meteorological conditions encountered throughout the study makes the data representative.

A. Objectives - The purpose of these studies is to investigate the temperature and wind structure of the atmosphere over Tract C-a by season. These data are used in modeling studies to predict the environmental impact of future oil shale development.

B. Methods - During each period, four soundings per day were attempted to investigate the formation and break up of inversions. During the fall 1974 study, inclement weather forced cancellation of the flights on seven of the 15 study days. The operational plans were changed, therefore, for the remaining upper air studies. If soundings were cancelled due to either instrument problems or inclement weather, another day was added to the schedule at the end of the planned study period. This effectively ensured a minimum of 15 days of data for each study. For the winter, spring and summer studies, a successful sounding day was defined as one having a minimum of two temperature profile measurements with at least one of these extending into the canyons below the tract.

The following techniques and instrumentation were used to obtain the temperature profiles and the wind velocities and directions aloft. A detailed discussion of these techniques and instrumentation can be found in the progress and annual RBOSP reports referenced previously.

1. Temperature Profiles - The vertical temperature structure from the surface to 13,000 ft above MSL was determined four times per day with a sensitive shielded thermistor mounted on the wind strut of a light aircraft. The four flights were made at approximately 0500, 0800, 1100, and 1700 hours MST. Daytime soundings were made to within 100 ft of the surface when safety considerations permitted. Flights were also made in the Piceance Canyon and Corral Gulch at 0500, 0800, and 1100 hours MST to determine the temperature structure of the air at elevations lower than the tract.

Temperatures were recorded with an EG&G Model 702 Portable Temperature Recorder which is designed to achieve high-resolution temperature recordings from a moving vehicle. The unit is capable of measuring temperatures from -30^{o} to $+32^{o}$ C with an absolute accuracy of more than $\pm 0.2^{o}$ C. For this operation, the unit was calibrated to within $\pm 0.1^{o}$ C.

The flight path of the aircraft was duplicated as closely as possible for each flight. When it was possible to fly within 200 ft above the surface near the top of the Site 1 meteorological tower, it was done to check the accuracy of the aircraft altimeter settings. In all cases, the altimeter indicated an elevation of 7,600 $\pm$50 ft above MSL during the Tract C-a tower fly-by. The elevation of the top of the tower is 7590 ft above MSL.

During the 0500, 0800, and 1100 MST soundings over Tract C-a, the flight path involved a slow, gradual descent from approximately 13,000 ft above MSL to a top-of-tower fly-by. The aircraft continued to descend into Corral Gulch normally reaching to within 50 ft of the surface at the confluence of Corral Gulch and Yellow Creek. This required that the temperature measurement made at a level comparable with the elevation of the

base of the tower be horizontally displaced from the tower itself. Because of this, data below 7,600 ft cannot accurately be termed "vertical" temperature soundings, even though the 10 ft per sec rate of descent was maintained along the horizontal flight path. The aircraft's normal descent from 13,000 ft took place in an approximately 1-mi diameter spiral at a rate of about 10 ft per sec. Altitude markings were made by an observer on the temperature chart in real time. The pilot attempted to maintain a constant rate of descent; however, this was not always possible due to turbulence. For this reason, temperature and altitude readings were taken from the charts only at points marked with a distinct altitude. No interpolations between markings were made.

To investigate the existence of measurable horizontal temperature gradients under the presence of an inversion, flights were flown at constant altitudes through the Piceance Creek Valley. These flights, only taken in the presence of an inversion, started at the confluence of Ryan Gulch and the Piceance Creek Valley and terminated just over Redd Ranch. They were flown at constant altitudes of either 6,400 or 6,500 ft above MSL, depending upon safety considerations (100 or 200 ft above the surface, respectively).

2. Winds Aloft -The vertical wind structure from the surface of the tract (i.e., 7,400 ft above MSL) to 13,000 ft above MSL or cloud base was determined four times per day with "30-gram" pilot balloons in conjunction with a theodolite. The balloons were released at approximately 0500, 0800, 1100, and 1700 hours MST in conjunction with temperature soundings.

C. Data Summary and Discussion -

1. Temperature Profile Data - Upper air temperature profiles were analyzed to determine the relationship between the approximate stack height (300 ft) and the mixing layer height (normally taken as the upper extent of a surface based inversion or the base of an elevated inversion). Points H_1 and H_2 used in the analysis are defined in the idealized temperature

profile illustrated in Figure 3-6-27. H_1 and H_2 are upper and lower tangental crossings which represent different cases of the boundaries of the mixing layer. The mixing layer height is important because it determines the upper extent to which a buoyant plume can penetrate, if an elevated inversion defines the mixing layer height. In addition, for a surface based inversion, emissions discharged above the mixing layer height do not affect ground level concentrations.

Several cases observed during data analysis are shown schematically in Figure 3-6-28 to illustrate the relationships between H_1, H_2, and stack height, S. The value of stack height, S, was chosen as 300 ft based on the proposed facility plans. The seasonal average mixing layer heights were determined and are presented in Table 3-6-19. Also shown on this table are the mean times of inversion break up for each season. These times were derived from temperature profiles in which a mixing layer existed during one sounding and did not exist in the next chronological sounding. The times of the two soundings were arithmetically averaged to define the mean time of inversion layer break up for that day. Figures 3-6-29 through 3-6-32 are representative seasonal temperature profiles extracted from the four upper air studies. Some data point symbols were not plotted on these figures to preserve clarity. Tables 3-6-20 and 3-6-21 present the values of H_1 and H_2 measured for all soundings. Because the level used to reference H_1 and H_2 was chosen at 7,200 ft above MSL (elevation of proposed plant site), it is possible to obtain negative values for H_1 and H_2. This can only happen when the temperature structure of interest is contained entirely within the canyons below the level of the tract. This phenomenon was observed in a significant number of cases; therefore, the average mixing layer heights in Table 3-6-19 would decrease if the reference level chosen for H_1 and H_2 were at the bottom of Piceance Creek Canyon (elevation 6,300 ft above MSL).

The mixing layer heights reported in Table 3-6-19 are not necessarily the heights of surface based inversions, but reflect altitudes of elevated inversions as well. To ensure that only significant mixing layers were

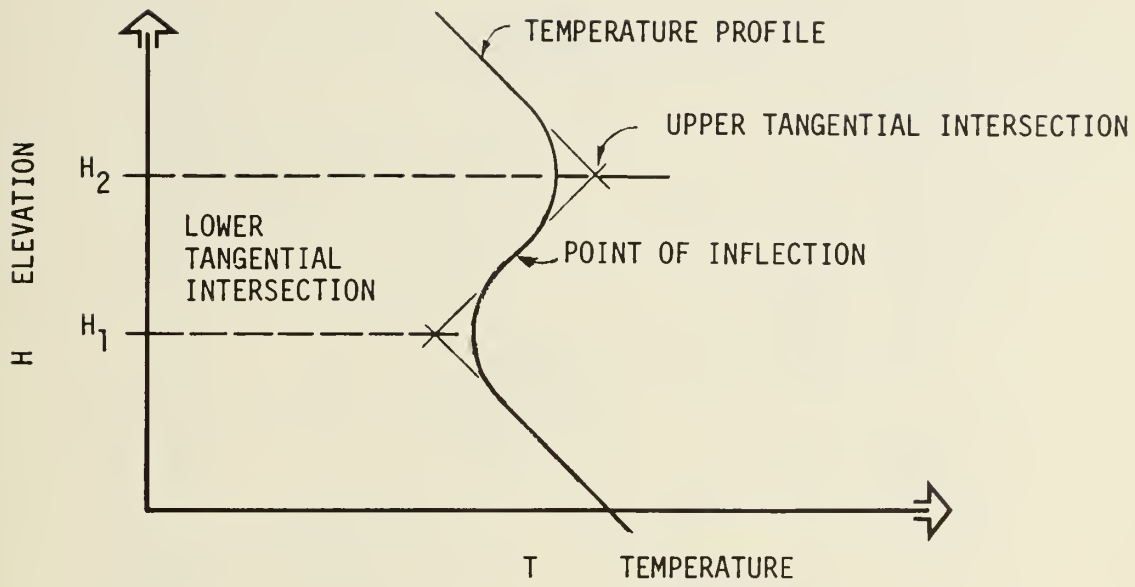


Figure 3-6-27

DETAILED TEMPERATURE PROFILE (IDEALIZED INVERSION)

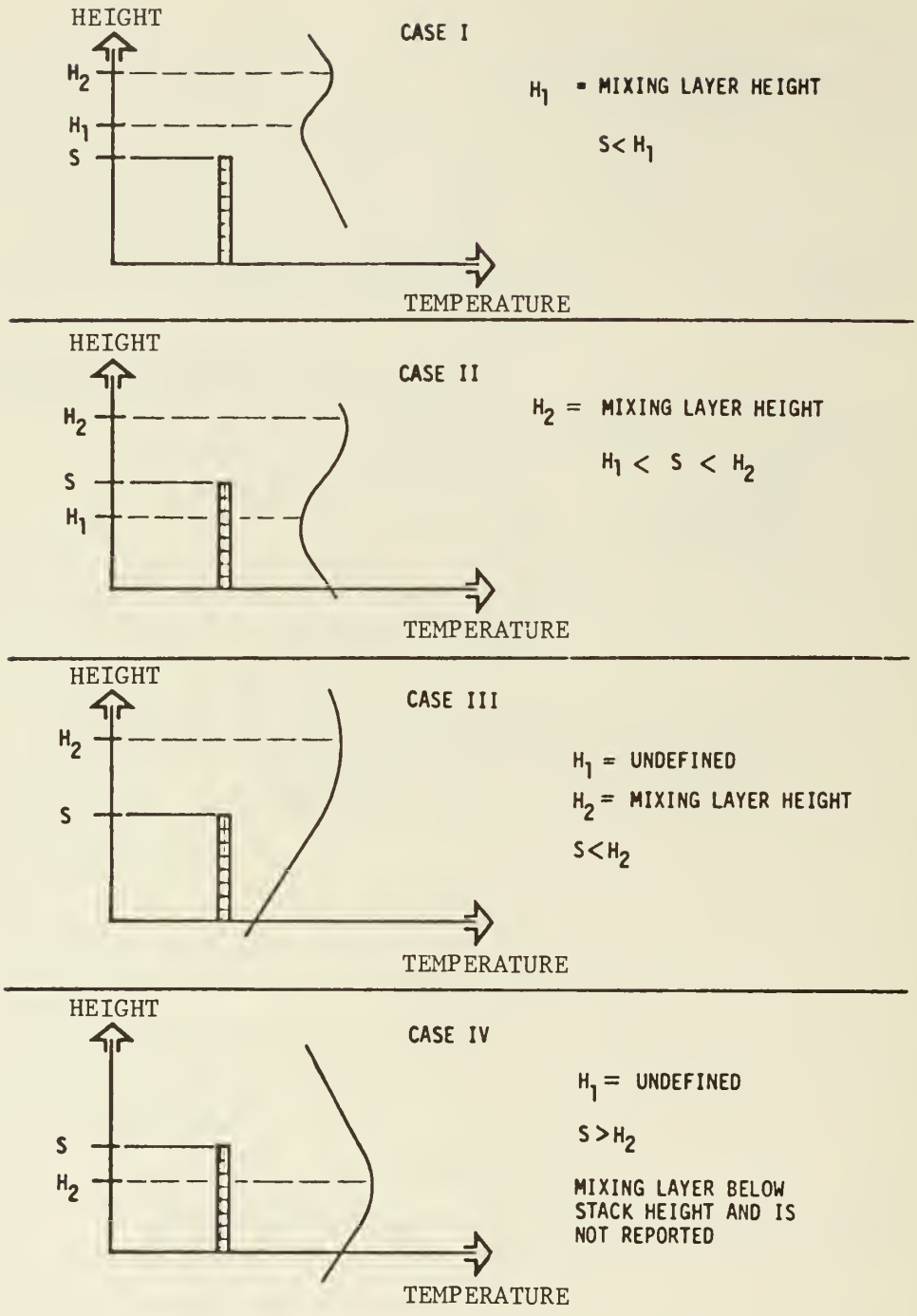


Figure 3-6-28
MIXING LAYER DETERMINATIONS

Figure 3-6-19

SEASONAL AVERAGES - MIXING LAYER HEIGHT AND TIME TO INVERSION BREAKUP, RBOSP

SEASON	AVERAGE MIXING LAYER HEIGHT FOR A 300 FOOT STACK (RELATIVE TO 7200 FEET)*								MEAN TIME TO INVERSION BREAKUP (MST)
	Sounding 1		Sounding 2		Sounding 3		Sounding 4		
	Height -Feet-	Freq. of Occurrence	Height -Feet-	Freq. of Occurrence	Height -Feet-	Freq. of Occurrence	Height -Feet-	Freq. of Occurrence	
Fall	642	.67	400**	.09	--	--	--	--	7:50
Winter	2371	.47	950	.27	2900**	.13	2788	.27	11:45
Spring	3067	.20	--	--	--	--	--	--	6:50
Summer	588	.20	--	--	--	--	--	--	7:00
Annual	1477		950				2788		

* Data only considered for inversions above level of tract (7200')

**Based on less than 3 occurrences

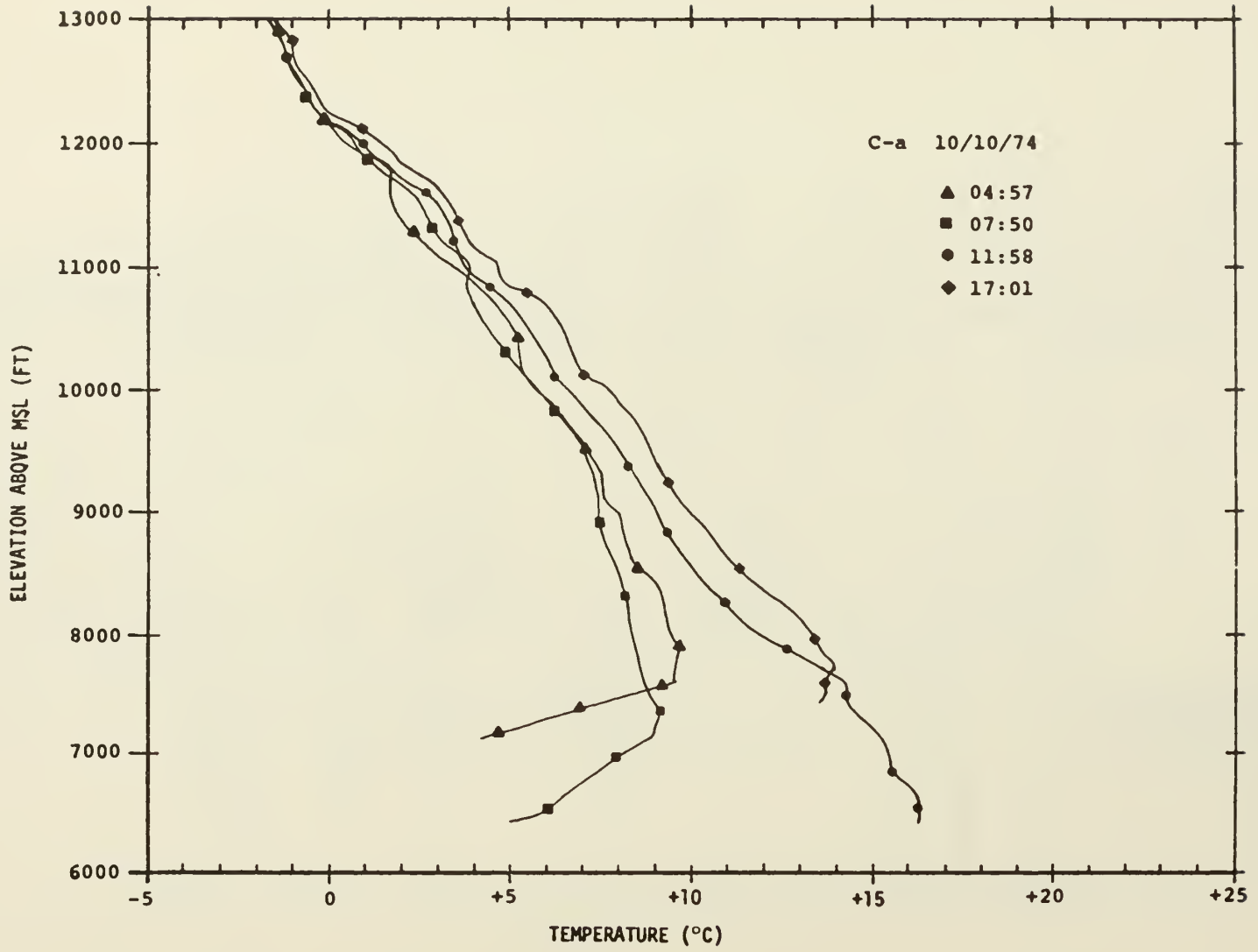


Figure 3-6-29

TYPICAL FALL TEMPERATURE PROFILE, RBOSP

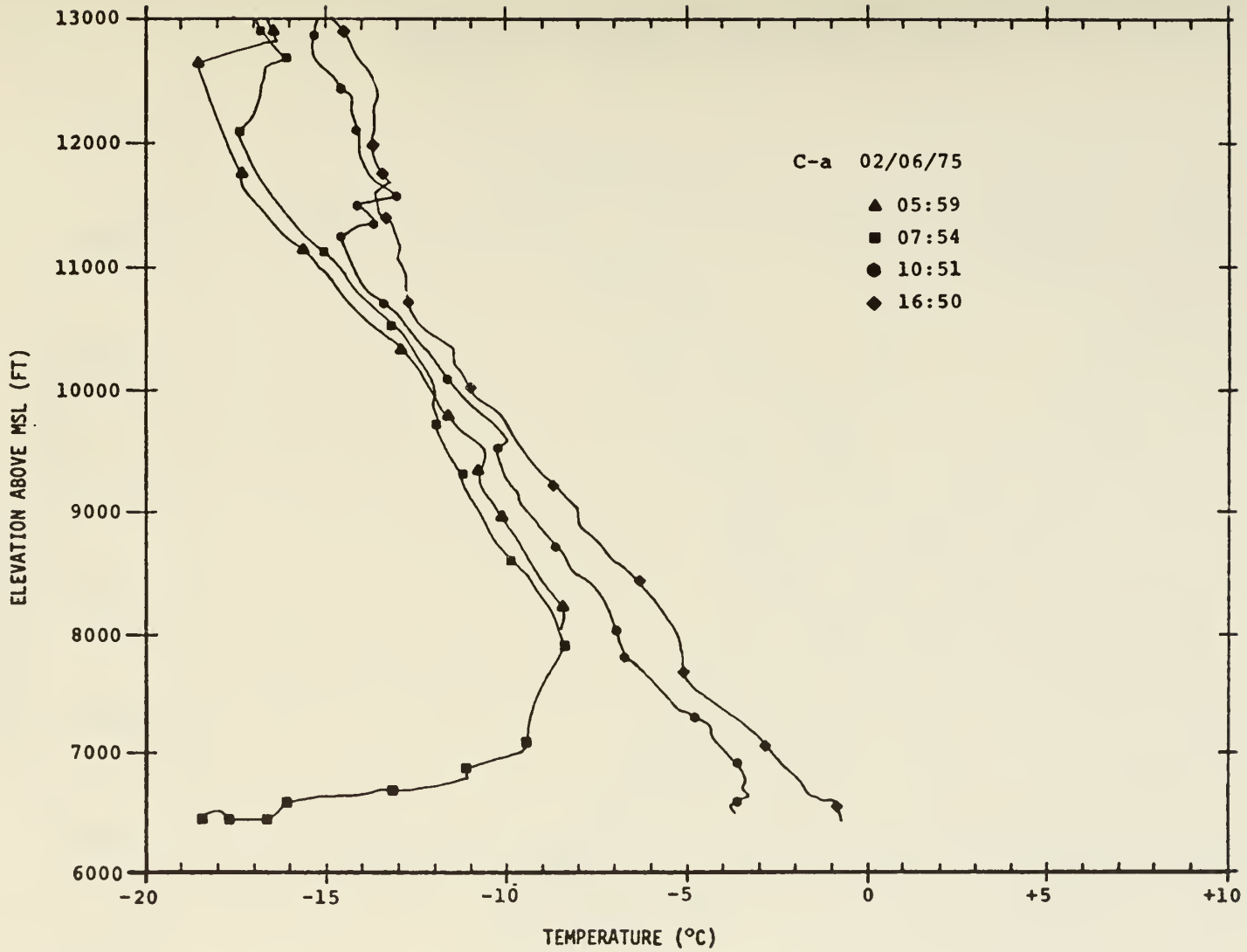


Figure 3-6-30
TYPICAL WINTER TEMPERATURE PROFILE, RBOSP

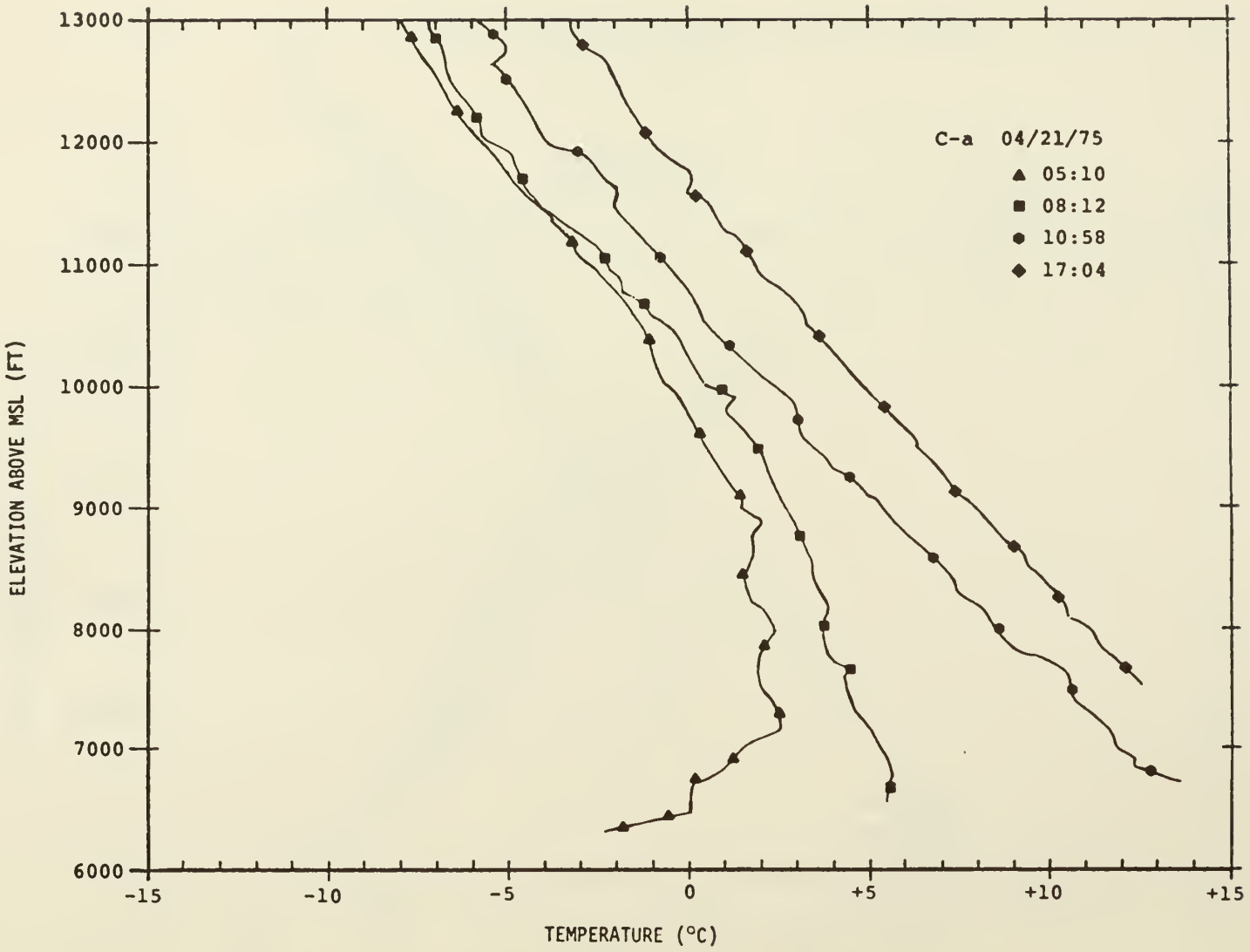


Figure 3-6-31

TYPICAL SPRING TEMPERATURE PROFILE, RBOSP

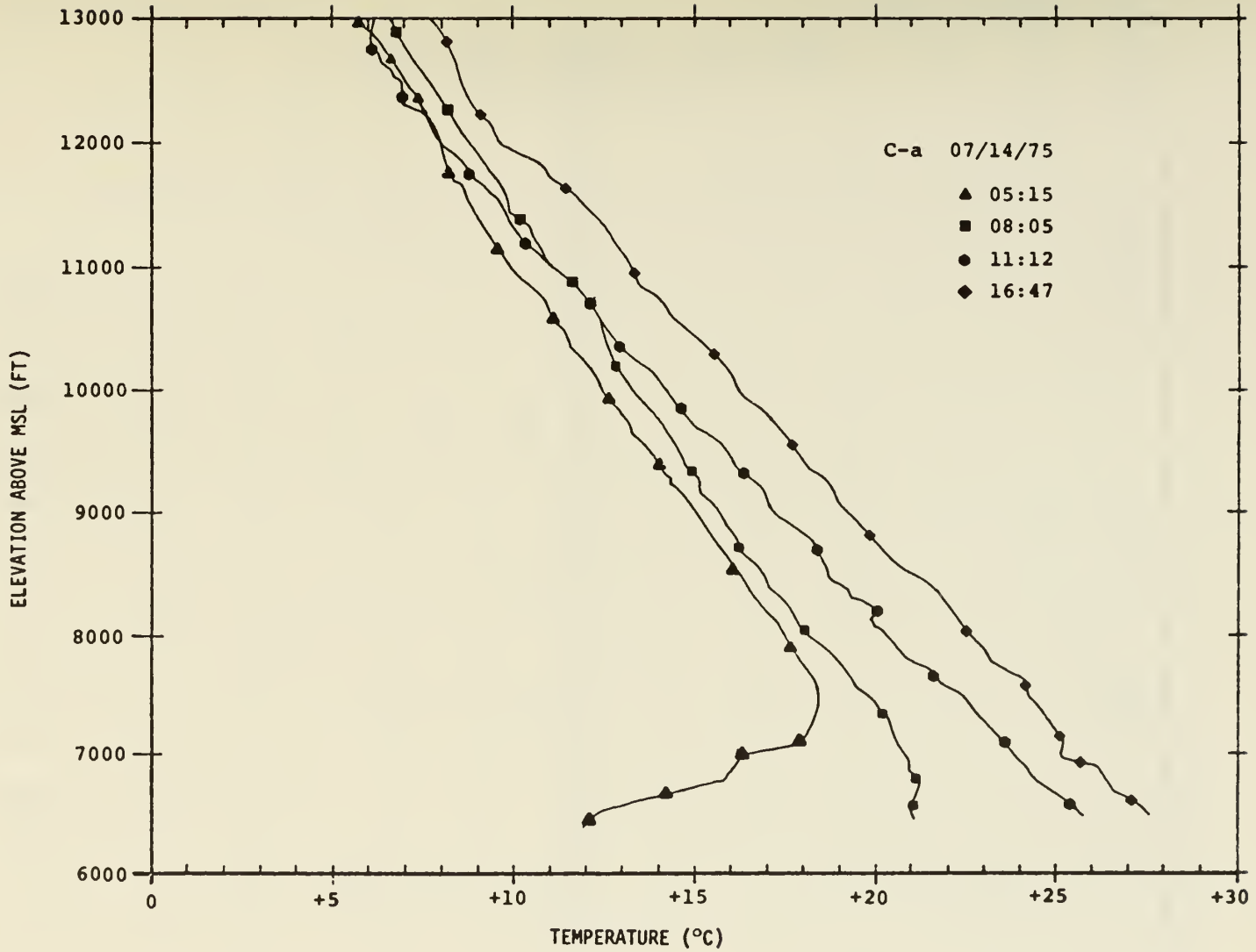


Figure 3-6-32

TYPICAL SUMMER TEMPERATURE PROFILE, RBOSP

Table 3-6-20
FALL/WINTER H_1 AND H_2 DATA, RBOSP
H_1 AND H_2 IN FEET

FALL 1974

OATE		Sounding			
		#1	#2	#3	#4
October 1, 1974	H_1	--	--	--	--
	H_2	400	--	--	--
October 2, 1974	H_1	--	--	--	--
	H_2	350	--	--	--
October 3, 1974	H_1	--	--	--	msg
	H_2	500	00	--	msg
October 7, 1974	H_1	--	--	--	--
	H_2	100	--	--	--
October 8, 1974	H_1	--	--	--	msg
	H_2	--	150	--	msg
October 9, 1974	H_1	--	--	--	--
	H_2	00	--	--	--
October 10, 1974	H_1	--	--	--	--
	H_2	150	-350	--	--
October 11, 1974	H_1	--	--	msg	msg
	H2	400	-500	msg	msg
October 13, 1974	H_1	msg	msg	--	--
	H_2	msg	msg	--	--
October 14, 1974	H_1	--	400	--	--
	H_2	1800	1200	--	--
October 15, 1974	H_1	--	--	--	--
	H_2	400	00	-900	--

WINTER 1975

OATE		Sounding			
		#1	#2	#3	#4
January 20, 1975	H_1	msg	--	--	2300
	H_2	msg	-350	00	3000
January 23, 1975	H_1	2300	--	--	--
	H_2	2700	400	--	--
January 24, 1975	H_1	--	-600	--	2400
	H_2	1200	-300	--	2550
January 25, 1975	H_1	msg	--	--	--
	H_2	msg	--	--	--
January 26, 1975	H_1	300	--	--	--
	H_2	500	--	--	--
January 29, 1975	H_1	2000	--	--	3150
	H_2	2300	00	-500	4100
January 31, 1975	H_1	msg	msg	--	--
	H_2	msg	msg	--	--
February 1, 1975	H_1	msg	--	--	--
	H_2	msg	-700	--	--
February 2, 1975	H_1	1900	--	--	--
	H_2	2100	300	--	--
February 3, 1975	H_1	--	--	--	--
	H_2	--	-50	--	--
February 4, 1975	H_1	--	--	--	msg
	H_2	--	00	--	msg
February 6, 1975	H_1	5400	--	--	--
	H_2	5600	200	--	--
February 7, 1975	H_1	msg	msg	3600	--
	H_2	msg	msg	3650	--
February 8, 1975	H_1	3800	--	2200	3300
	H_2	400	-800	3000	3900
February 9, 1975	H_1	--	2800	msg	msg
	H_2	--	3200	msg	msg

-- H_1 or H_2 not defined

msg = missing

Table 3-6-21

SPRING/SUMMER H_1 AND H_2 DATA, RBOSP

H_1 AND H_2 IN FEET

SPRING 1975

DATE		Sounding			
		#1	#2	#3	#4
April 14, 1975	H_1	--	--	--	--
	H_2	--	--	--	--
April 15, 1975	H_1	--	--	--	--
	H_2	--	--	--	--
April 16, 1975	H_1	--	--	--	msg
	H_2	--	--	--	msg
April 18, 1975	H_1	msg	msg	--	--
	H_2	msg	msg	--	--
April 19, 1975	H_1	4200	--	--	--
	H_2	4300	--	--	--
April 20, 1975	H_1	--	--	--	--
	H_2	-300	--	--	--
April 21, 1975	H_1	--	--	--	--
	H_2	-200	--	--	--
April 22, 1975	H_1	--	--	--	--
	H_2	--	--	--	--
April 23, 1975	H_1	--	--	--	--
	H_2	00	--	--	--
April 24, 1975	H_1	--	--	--	--
	H_2	-100	--	--	--
April 25, 1975	H_1	4700	4400	msg	msg
	H_2	5100	5200	msg	msg
April 28, 1975	H_1	-600	--	--	msg
	H_2	-250	--	--	msg
April 29, 1975	H_1	--	--	--	msg
	H_2	-350	--	--	msg
April 30, 1975	H_1	--	--	--	--
	H_2	--	--	--	--
May 1, 1975	H_1	--	--	--	msg
	H_2	300	--	--	msg

SUMMER 1975

DATE		Sounding			
		#1	#2	#3	#4
July 12, 1975	H_1	--	--	--	--
	H_2	700	--	--	--
July 13, 1975	H_1	--	--	--	--
	H_2	-500	--	--	--
July 14, 1975	H_1	-1200	--	--	--
	H_2	00	--	--	--
July 15, 1975	H_1	-1000	--	--	--
	H_2	-200	--	--	--
July 16, 1975	H_1	--	--	msg	msg
	H_2	--	--	msg	msg
July 17, 1975	H_1	--	--	--	--
	H_2	300	--	--	--
July 18, 1975	H_1	--	--	--	--
	H_2	-250	--	--	--
July 19, 1975	H_1	--	--	--	msg
	H_2	-250	--	--	msg
July 20, 1975	H_1	--	--	--	--
	H_2	00	--	--	--
July 21, 1975	H_1	--	--	--	--
	H_2	-500	--	--	--
July 22, 1975	H_1	--	--	--	--
	H_2	-250	--	--	--
July 23, 1975	H_1	--	--	--	--
	H_2	-600	--	--	--
July 24, 1975	H_1	--	--	--	--
	H_2	900	--	--	--
July 25, 1975	H_1	--	--	--	--
	H_2	-50	-200	--	--
July 26, 1975	H_1	--	--	--	msg
	H_2	450	-200	--	msg

-- H_1 or H_2 not defined

msg = missing

included in the average height determination, an inversion had to be at least 200 ft deep with a total temperature change of at least 1^{o} C from top to bottom of the interval.

The behavior of the mixing layer height by season is interesting. The first sounding during the summer and fall shows a much lower mixing height with a much higher frequency of occurrence than the corresponding soundings during the winter and spring. Average inversion breakup during the winter occurred at a significantly later time of the day than any of the other seasons probably because of the reduced insolation available to "burn off" these inversions and the increased albedo (snow cover).

A quantitative comparison of the temperature difference over 100 m (328 ft) centered at an altitude of 1,000 ft above the surface between the sets of seasonal soundings is given in Tables 3-6-22 and 3-6-23. The "surface" was chosen as 7,200 ft on the ridge-like regions. Stability was classified according to the scheme given in Table 3-6-14. The atmosphere in the early morning was slightly stable or stable and by late morning and afternoon turned to neutral categories.

2. Winds Aloft Data - Wind speed and direction data from the upper air measurements were vectorially averaged for each seasonal study. Six altitudes were selected and averages were made for each of these. Table 3-6-24 shows these reduced data as a function of season and altitudes. Figures 3-6-33 through 3-6-36 are representative pilot balloon soundings for the four seasons. Horizontal distances are represented by circular chart divisions. The horizontal distance scale associated with circular chart divisions is referenced in the legend for each sounding. Some points were not plotted on these figures to preserve clarity and prevent crowding of the plots.

Data presented in Table 3-6-24 show the expected increase in wind speed with altitude, although there are two exceptions. The decrease in average wind speed between 11,000 and 12,000 ft above MSL for the spring season is

Table 3-6-22

STABILITY AT 1000 FEET ABOVE THE SURFACE, FALL AND WINTER STUDIES
(NUMBERS IN PARENTHESES ARE TEMPERATURE CHANGES (°C) OVER A 100-METER INTERVAL), RBOSP

FALL 1974

OATE	Sounding			
	#1	#2	#3	#4
October 1, 1974	O(-0.78)	O(-0.94)	D(-0.82)	D(-0.97
October 2, 1974	O(-0.97)	O(-0.67)	O(-0.96)	O(-0.89)
October 3, 1974	O(-1.04)	O(-1.16)	O(-1.05)	msg
October 7, 1974	E(0.15)	E(0.17)	C(-1.55)	C(-1.69)
October 8, 1974	D(-0.88)	O(-0.58)	D(-1.36)	msg
October 9, 1974	O(-1.04)	E(-0.32)	O(-0.92)	D(-0.98)
October 10, 1974	O(-0.75)	E(-0.04)	O(-0.72)	D(-0.97)
October 11, 1974	O(-0.76)	D(-0.27)	msg	msg
October 13, 1974	msg	msg	D(-1.19)	O(-0.77)
October 14, 1974	E(0.00)	E(0.05)	D(-1.06)	O(-1.06)
October 15, 1974	D(-0.67)	D(-0.55)	O(-0.87)	O(-0.77)

WINTER 1975

DATE	Sounding			
	#1	#2	#3	#4
January 20, 1975	msg	E(0.00)	O(-0.93)	E(-0.37)
January 23, 1975	E(0.02)	E(-0.20)	E(-0.38)	O(-0.67)
January 24, 1975	E(1.41)	E(-0.46)	D(-0.54)	O(-0.52)
January 25, 1975	msg	O(-0.74)	O(-0.76)	O(-0.52)
January 26, 1975	E(0.70)	D(-0.56)	E(-0.03)	msg
January 29, 1975	O(-0.62)	E(-0.50)	D(-.84)	O(-0.70)
January 31, 1975	msg	msg	D(-0.50)	D(-0.62)
February 1, 1975	msg	O(-0.50)	D(-0.60)	O(-0.70)
February 2, 1975	E(-0.20)	D(-0.83)	D(-0.79)	O(-0.84)
February 3, 1975	O(-0.92)	O(-0.57)	O(-0.80)	D(-0.37)
February 4, 1975	O(-0.67)	O(-0.73)	O(-0.96)	msg
February 6, 1975	O(-0.67)	E(-0.45)	D(-0.60)	O(-0.87)
February 7, 1975	msg	msg	O(-0.58)	E(-0.40)
February 8, 1975	E(-0.46)	E(-0.03)	O(-0.96)	O(-0.95)
February 9, 1975	E(0.46)	E(-0.36)	msg	msg

msg = missing

Table 3-6-23

STABILITY AT 1000 FEET ABOVE THE SURFACE, SPRING AND SUMMER STUDIES
(NUMBERS IN PARENTHESES ARE TEMPERATURE CHANGES (^{o}C) OVER A 100-METER INTERVAL), RBOSP

SPRING 1975

OATE	Sounding			
	#1	#2	#3	#4
April 14, 1975	D(-0.54)	E(-0.49)	E(-0.27)	D(-0.81)
April 15, 1975	0(-0.70)	0(-0.73)	D(-1.01)	D(-0.90)
April 16, 1975	0(-0.97)	0(-1.16)	D(-1.11)	msg
April 18, 1975	msg	msg	D(-0.87)	D(-0.88)
April 19, 1975	0(-0.67)	D(-0.82)	0(-1.24)	D(-0.89)
April 20, 1975	0(-0.84)	0(-0.73)	D(-0.54)	D(-0.82)
April 21, 1975	E(-0.44)	E(-0.39)	D(-0.80)	D(-0.94)
April 22, 1975	0(-0.55)	0(-0.88)	D(-0.67	D(-1.03)
April 23, 1975	0(-0.82)	0(-0.93)	0(-1.34)	0(-0.74)
April 24, 1975	0(-0.62)	0(-0.91)	0(-1.05)	0(-0.51)
April 25, 1975	0(-0.76)	0(-1.22)	msg	msg
April 28, 1975	0(-0.89)	0(-1.02)	0(-0.91)	msg
April 29, 1975	0(-0.67)	0(-1.00)	0(-0.94)	msg
April 30, 1975	D(-0.90)	0(-0.97)	0(-0.90)	0(-0.85)
May 1, 1975	D(-0.74)	0(-0.96)	0(-1.17)	msg

SUMMER 1975

OATE	Sounding			
	#1	#2	#3	#4
July 12, 1975	D(-0.53)	0(-0.54)	0(-1.10)	D(-0.89)
July 13, 1975	0(-0.59)	0(-0.60)	0(-1.01)	0(-1.03)
July 14, 1975	0(-0.72)	0(-0.75)	0(-0.89)	D(-1.34)
July 15, 1975	E(-0.06)	E(-0.25)	D(-1.33)	0(-0.86)
July 16, 1975	E(0.83)	0(-0.75)	msg	msg
July 17, 1975	E(-0.34)	0(-0.76)	0(-0.89)	D(-1.11)
July 18, 1975	E(-0.22)	D(-1.17)	0(-1.17)	D(-0.81)
July 19, 1975	D(-0.69)	D(-0.97)	msg	C(-1.51)
July 20, 1975	0(-0.70)	0(-0.74)	0(-1.03)	0(-0.63)
July 21, 1975	0(-0.52)	0(-0.52)	D(-1.26)	0(-1.08)
July 22, 1975	0(-0.63)	D(-0.63)	0(-1.24)	0(-0.77)
July 23, 1975	E(-0.27)	D(-0.93)	0(-0.94)	0(-1.03)
July 24, 1975	D(-0.84)	E(-0.45)	0(00.65)	D(-1.41)
July 25, 1975	0(-0.67)	0(-0.66)	0(-0.90)	msg
July 26, 1975	E(-0.34)	0(-0.66)	0(-1.36)	msg

msg = missing

Table 3-6-24

SEASONAL AVERAGE WIND SPEED AND DIRECTION FOR SELECTED ALTITUDES, RBOSP

SEASON	AVERAGE WIND SPEED/DIRECTION AT						
	8000'	9000'	10000'	11000'	12000'	13000'	AVERAGE
Fall	4.22/247.60	7.27/246.64	8.83/260.96	12.31/261.04	12.26/263.40	14.47/269.10	9.81/260.78
Winter	17.80/243.89	22.18/248.77	26.72/257.38	27.93/269.34	29.47/273.98	30.29/278.04	25.15/264.01
Spring	9.21/220.20	11.57/224.26	13.39/229.00	19.73/227.48	17.36/237.07	19.89/242.04	15.07/231.56
Summer	2.40/271.20	2.80/278.02	3.93/279.86	5.15/273.34	6.14/275.79	7.15/275.39	4.59/275.64
Annual	8.17/239.81	10.64/243.78	12.78/252.54	15.42/255.67	15.70/262.51	17.33/266.16	13.18/255.60

Note: Units (MPH/Degrees)

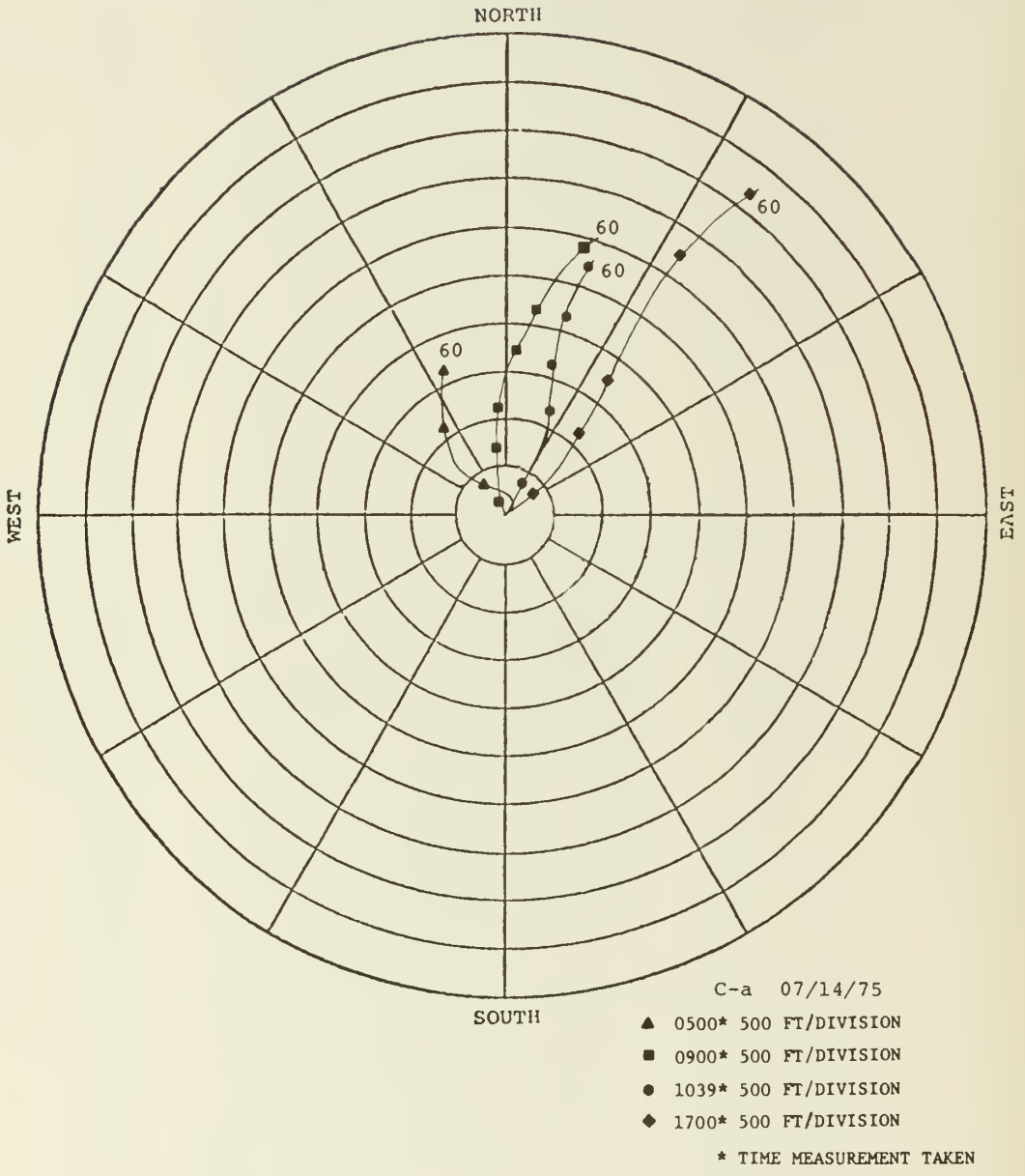


Figure 3-6-33

TYPICAL SUMMER PILOT BALLOON SOUNDINGS, RBOSP

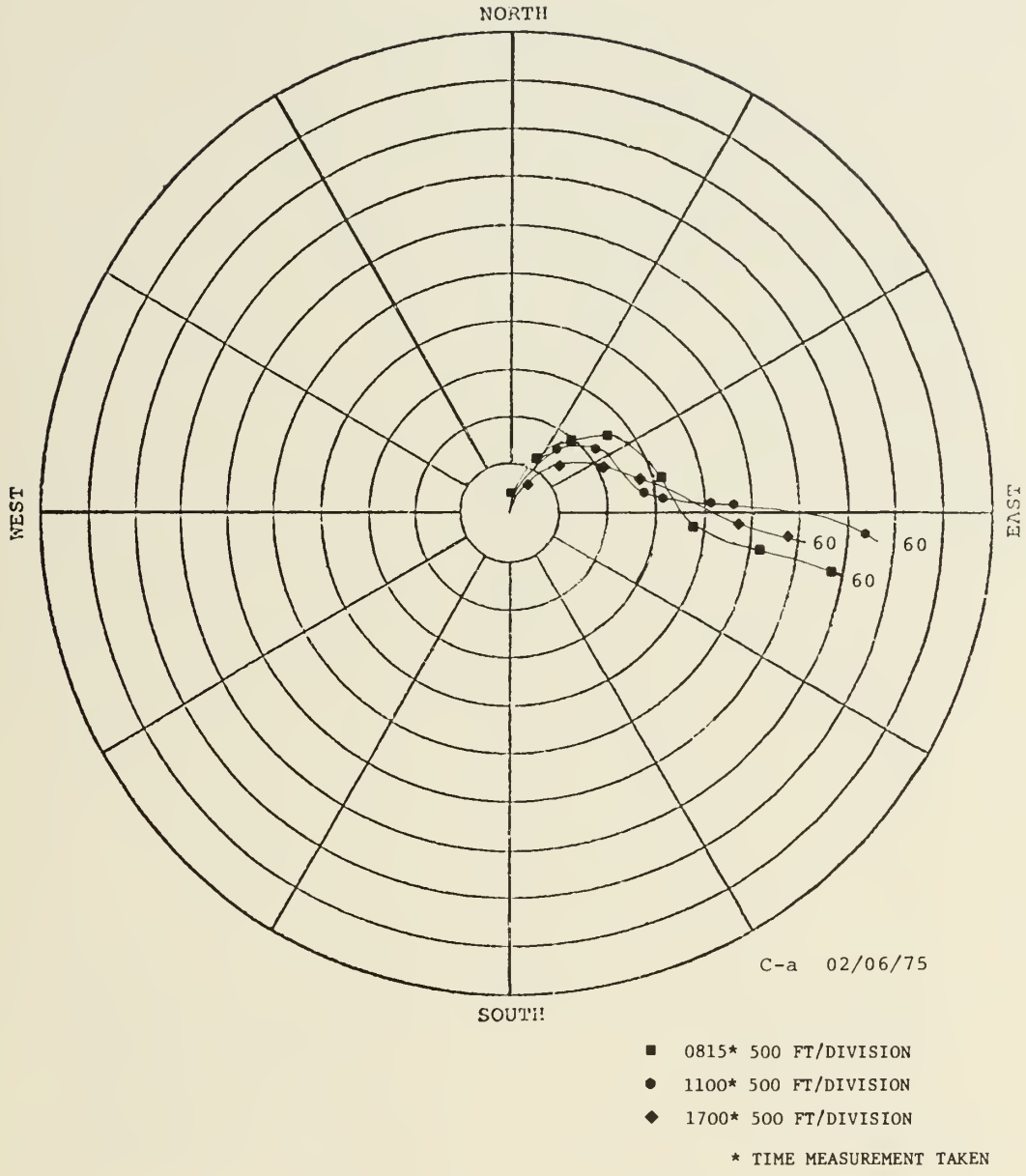


Figure 3-6-34

TYPICAL WINTER PILOT BALLOON SOUNDINGS, RBOSP

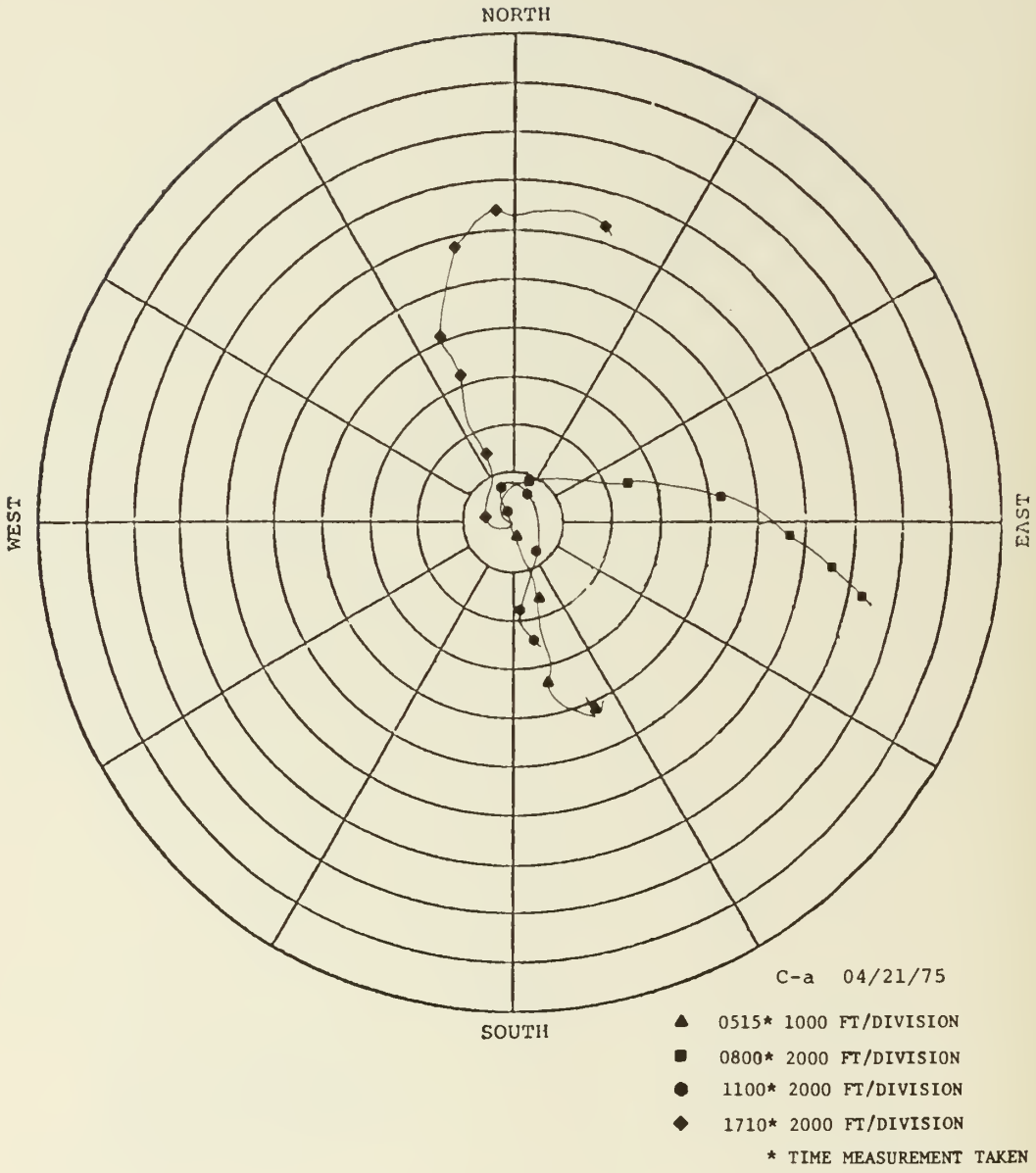


Figure 3-6-35

TYPICAL SPRING PILOT BALLOON SOUNDINGS, RBOSP

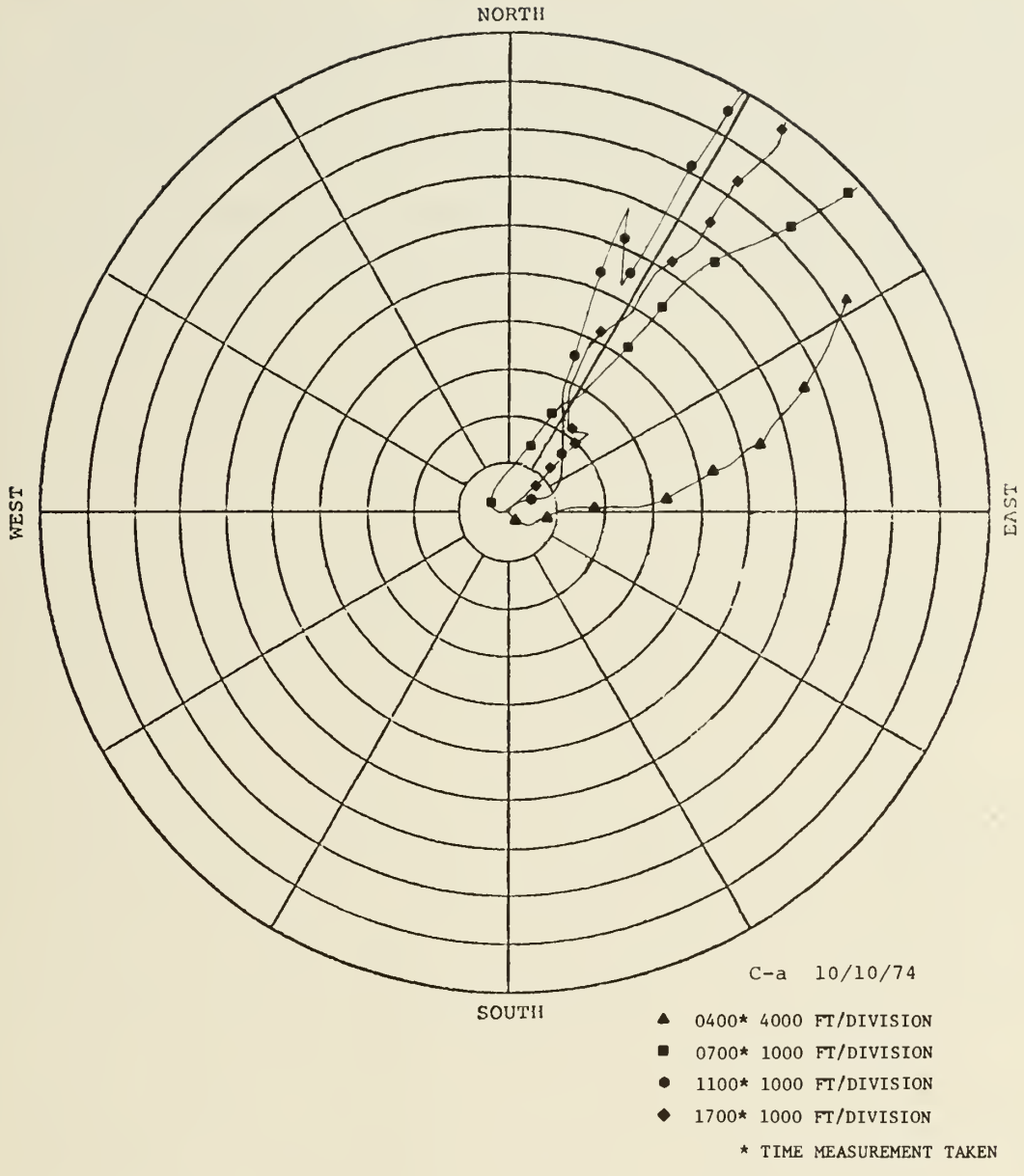


Figure 3-6-36

TYPICAL FALL PILOT BALLOON SOUNDINGS, RBOSP

probably an indication that the pilot balloons reached the upper level of the planetary boundary layer at this altitude. The low altitude (11,000 to 12,000 ft) decrease in mean wind speed with height during the fall sampling period is small and may be associated with the high frequency of sounding days associated with precipitation during the fall study. All seasons show the general clockwise turning of the wind direction with increasing height (Ekman effect). The summer and fall mean wind speeds are significantly lower than the corresponding speeds during winter or spring.

6.3 TRACER STUDIES

A tracer study is performed to obtain data for comparison with the analytical dispersion model (Section 9 Chapter 5). This provides further information for enhancing model accuracy where rough terrain may exert influences on the airflow that are difficult to simulate mathematically.

The dispersion model can be summarized as follows. Diffusion models are mathematical simulations of atmospheric processes that are responsible for the transport, dispersion, and diffusion of gaseous substances in the project area. The mathematical simulations are based upon equations which utilize statistical meteorological data. These meteorological data are obtained from the lower air studies, upper air studies, and long term records of meteorological data from nearby weather stations. The air quality studies measure the pre-development pollutant concentrations in the project area and constitute the historical baseline. The dispersion model utilizes the meteorological data, baseline air quality data, and facility emissions to predict the future air quality in the project area.

Tracer studies simulate the release of emissions into the atmosphere from the proposed plant and measure the actual concentrations resulting from those emissions in the project area. Typically, exotic gases such as sulfur hexafluoride, one of the fluorocarbons, or silver iodide are released into the atmosphere at the plant site in controlled amounts. The resulting concentrations in the study area are then measured with analytical devices. The meteorological parameters during the tracer study are carefully measured. This type of study program is usually repeated for several different "weather conditions" to gather information on transport, dispersion and diffusion in the area under a variety of atmospheric conditions.

It is expected that the tracer study results will show that the assumptions and dispersion coefficients used in the dispersion modeling (Section 9 Chapter 5) are much more conservative than necessary. Therefore, modeling with the information obtained from the air specific tracer studies would

lower predicted concentrations.

A tracer study, using silver iodide as the tracer substance, was performed on Tract C-a. The results from this study were highly biased, however, by fugitive dust in the area. A second study is planned for late spring or early summer 1976. Area specific knowledge gained during the first study will be used in designing this study to minimize biasing of the results by such area specific interferences.

6.4 PRECIPITATION

Precipitation studies at Tract C-a involve measurements for precipitation and snow course.

A. Objectives - Precipitation data are important for assessments of local ecology, hydrology, air quality, and water quality, and may also be used in operational planning of project activities. The types of precipitation data required for assessments are water-equivalent amounts for all precipitation, precipitation rate, time and duration of precipitation events, snow depth and equivalent water content of snow. Because of the large year-to-year variations in precipitation, the data are used with long-term precipitation records from nearby weather stations to extend the period of validity and estimate the representativeness of the data.

B. Methods - Convective storms which are frequent in summer are of very limited extent, thereby creating the need for the four widely separated measuring stations. One precipitation instrument is located at each of the four monitoring sites (Figure 3-6-1). Precipitation is measured using a Weather Measure Model P511-E heated tipping-bucket gauge. The P511-E gauge makes an indication for each 0.01 in. of water equivalent precipitation that occurs, either in liquid or solid form. Snow course measurements are made during the colder months to estimate the snow depth and equivalent water content of the snow at Site 1. Measurements of snow course are made periodically as determined by the presence of additional snow and the accessibility of the site. A snow sample tube and scale, Science Associates Model 540, is used. A detailed discussion of these techniques and instruments can be found in the progress and annual RBOSP reports referenced previously.

C. Literature Review - The precipitation pattern of northwestern Colorado is dependent upon local topography and elevation. Annual precipitation varies from greater than 76 cm near the Continental Divide to less than 26 cm in the far western edge of the state. Isopleths drawn from historical measurements

at 16 locations within Routt, Rio Blanco, and Moffat Counties are shown in Figure 3-6-37. Most of the precipitation during the summer and fall seasons comes from cloud bursts forced by topographical uplifting or thermal convection rather than from severe storms.

Table 3-6-25 shows monthly precipitation at selected locations with long term records in northwestern Colorado. As can be seen from the data, lower elevations receive somewhat more precipitation in the summer months. Moreover, the greatest portion of the precipitation which occurs above 8,000 ft elevation is in the form of snowfall.

D. Data Summary and Discussion - The annual precipitation measured in the Tract C-a area varied from 1.6 centimeters (0.65 inches) at Site 1 to 15.2 centimeters (5.97 inches) at Site 4 (Table 3-6-26). Compared with other data in the area (Figure 3-6-37), the annual precipitation at Site 4 appears to be slightly less than expected, while the annual precipitation at the other sites is much lower. Comparison of the monthly precipitation with snow course measurements (Table 3-6-27) indicates that the water content of the snow sample exceeded that measured at the precipitation gauge. Whereas these two measurements need not agree, such differences arouse suspicions. During the year, the anomalous precipitation measurements were noted. An additional calibration of precipitation gauges was performed using a second technique. The results indicated proper instrument operation. At this time there is no reconciliation of the noted differences, but further investigation of the apparent discrepancy is presently being conducted.

Precipitation data have also been taken by the USGS in the project area with two types of recording gauges (Section 3, Chapter 4). These date (Table 3-4-2) agree, in general, with those in Figure 3-6-37.

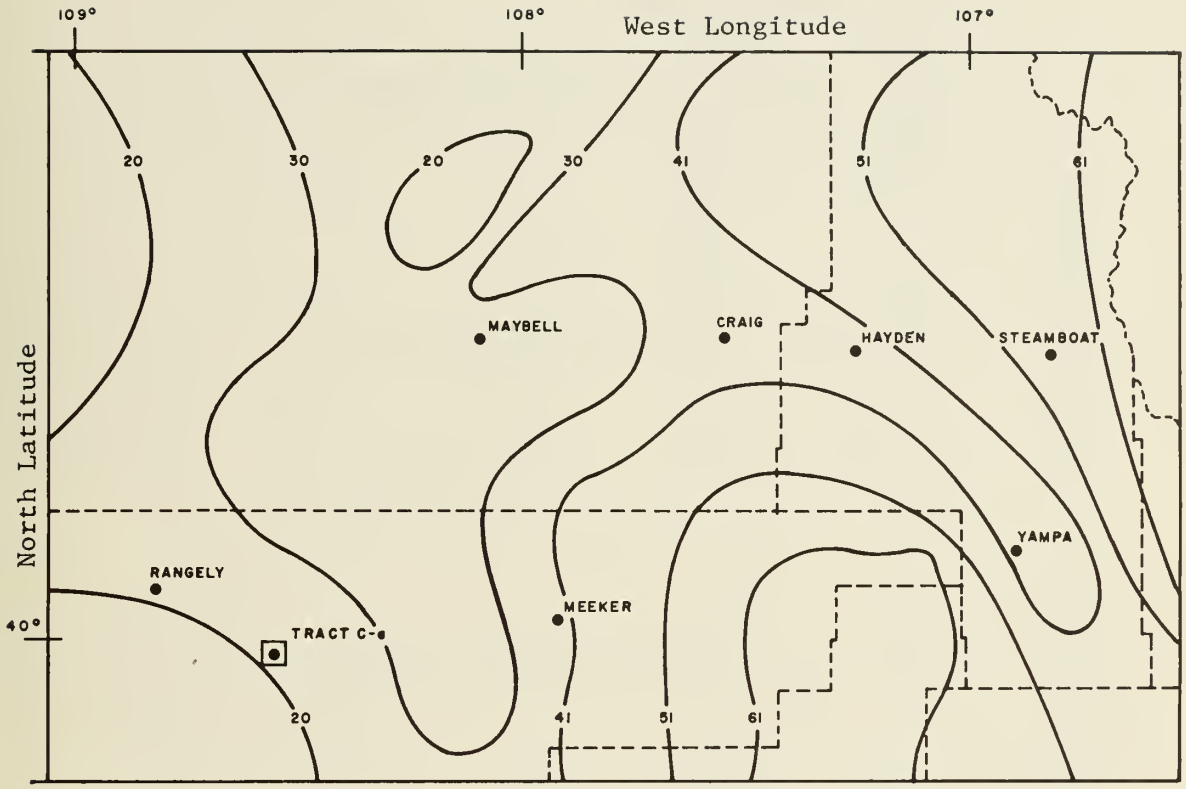


Figure 3-6-37

ISOPLETHS OF ANNUAL AVERAGE PRECIPITATION (CENTIMETERS)
IN NORTHWESTERN COLORADO

Source: Unpublished Data Summary

Table 3-6-25

PRECIPITATION SUMMARY FOR SELECTED SITES IN NORTHWEST COLORADO
(CENTIMETERS)

Station	Craig	Hamilton		Hayden	Little Hills	Marvine	Meeker		Rangely	Steamboat Springs
Elevation (feet above MSL)	6285	6230		6597	6148	7343	6242		5216	6879
Longitude	107° 33'	107° 37'		107° 13'	108° 12'	107° 31'	107° 54'		108° 47'	106° 52'
Latitude	40° 31'	40° 22'		40° 29'	40° 00'	40° 02'	40° 02'		40° 05'	40° 31'
	Prec.	Prec.	Snowfall	Prec.	Prec.	Prec.	Prec.	Snowfall	Prec.	Prec.
Jan	2.46	3.86	50	3.15	2.36	4.55	2.92	39	1.85	6.12
Feb	2.06	3.43	56	2.90	2.16	3.81	2.54	30	2.13	5.87
Mar	2.77	4.95	48	3.30	3.05	5.33	3.81	35	2.06	5.77
Apr	3.15	4.14	19	3.81	3.25	4.72	3.96	15	1.57	5.97
May	3.68	4.14	3	3.73	2.57	3.61	3.68	2	1.93	5.23
June	3.23	3.30	Trace	3.07	2.34	3.53	2.69	Trace	1.32	3.96
July	2.51	3.45	0	3.18	2.77	4.11	3.84	0	1.24	3.56
Aug	3.25	3.18	Trace	3.02	4.34	5.00	4.62	0	3.25	3.78
Sep	2.77	3.61	Trace	3.15	2.24	4.06	3.63	1	1.93	3.76
Oct	3.43	3.86	7	3.71	3.02	3.38	3.78	8	1.93	4.55
Nov	2.34	3.45	41	2.77	2.36	3.94	2.79	24	1.30	4.83
Dec	2.62	4.01	76	3.45	2.16	5.00	2.84	33	1.73	6.22
Annual Precip	34.26	45.39		39.24	32.61	51.05	41.12		22.25	59.62
Annual Snowfall	157		298	248				187	104	424

Source: Unpublished Data Summary

Table 3-6-26

SUMMARY FOR PRECIPITATION, RBOSP

Period	Precipitation (Inches)			
	Site 1	Site 2	Site 3	Site 4
February 1975	0.01	0.04	0.05	0.32
March 1975	0.12	0.01	0.15	0.92
April 1975	0.14	0.07	0.28	0.57
May 1975	0.13	0.12	0.68	1.09
June 1975	0.05	0.03	0.12	0.44
July 1975	0.04	0.03	0.08	0.56
August 1975	0.02	0.00	0.13	0.04
September 1975	0.01	0.18	0.03	0.13
October 1975	0.06	0.24	0.49	1.17
November 1975	0.05	0.01	0.41	0.46
December 1975	0.01	0.01	0.41	0.21
January 1976	0.01	0.00	0.06	0.06
Seasonal				
Winter (February)	0.01	0.04	0.05	0.32
Spring (March, April, May)	0.39	0.20	1.11	2.58
Summer (June, July, August)	0.11	0.06	0.33	1.04
Fall (September, October, November)	0.12	0.43	0.93	1.76
Winter (December, January)	0.02	0.01	0.47	0.27
Annual (February 1975 through January 1976)	0.65	0.74	2.89	5.97

Table 3-6-27

SUMMARY OF SNOW COURSE MEASUREMENTS AT SITE 1, RBOSP

Date of Sample	Total Snow Depth (In)	Sample (In of H_2O)
2/1/75	7.5	0.15
2/5/75	4.5	0.10
2/12/75	5.5	0.20
2/16/75	5.0	0.20
2/23/75	3.5	0.10
3/11/75	3.5	0.15
3/12/75	2.0	0.10
3/17/75	1.5	0.05
3/28/75	(Several inches but drifted)	*
4/1/75	7.4	0.20
4/9/75	(Several inches but drifted)	*
10/23/75	6.0	0.15
11/9/75	1.5	0.01
11/27/75	2.5	0.02
11/30/75	3.0	0.10
12/15/75	4.0	0.02
12/24/75	2.0	0.01
12/31/75	6.0	0.10
1/8/76	4.2	0.11
1/16/76	4.2	0.10
1/26/76	4.5	0.10

*Could not be determined

6.5 EVAPORATION

A. Objectives - The purpose of the evaporation measurements is to provide, on a periodic basis, an estimate of the rate of surface evaporation of water.

B. Methods - The concept of evaporation measurement is to measure the amount (in.) of water evaporated from the surface of a specially designed water pool under carefully measured ambient environmental conditions. The measurements needed for an evaporation determination are air temperature, relative humidity, wind movement, precipitation, water temperature, and amount of water necessary to replace that lost by evaporation. Air temperature, wind speed, and precipitation measurements are taken at Site 3 with the instruments used for lower air studies. Relative humidity data are taken from Site 1. To determine the evaporation rate an evaporation pan, Science Associates Model 242, is used. A detailed description of the equipment and methods can be found in the progress and annual RBOSP reports mentioned previously.

C. Literature Review - Evaporation data for the project area are virtually non-existent; however, the Environmental Data Service provides evaporation data within the Colorado River drainage. These data are shown in Table 3-6-28 with some additional measurements taken at the Hayden Station for the Yampa Valley Project. These data indicate that evaporation decreases with increasing altitude. Evaporation is greatest during the summer months of June and July. Correspondingly, cloud cover can be expected to be the least during these months.

D. Data Summary and Discussion - Evaporation data taken at Site 3 are presented in Table 3-6-29. The highest evaporation rate recorded at Tract C-a was 0.034 g/cm^2/hour which occurred during the week ending June 14, 1975. In general, the evaporation rates measured on tract are less than those reported from the Colorado River Basin, which are at an elevation of about 4,500 ft above MSL. Because of the higher air density and temperatures at the lower elevations, their higher evaporation rates are to be expected.

Table 3-6-28

EVAPORATION DATA FROM SIX STATIONS WITHIN THE COLORADO DRAINAGE REGION

Station	Length of Record (Years)	Elevation	Evaporation (centimeters) April	May	June	July	Aug	Sept	Oct
Grand Junction	12	1436 m.		32.7	44.0	44.3	37.2	29.4	18.3
Montrose	33	1777	14.4	19.5	24.8	24.6	19.4	15.8	9.6
Vallecito	25	2332	9.3	14.2	17.8	17.0	16.0	12.9	8.3
Green Mtn. Dam	24	2359			19.2	18.3	15.6	13.1	6.9
Grand Lake	23	2526			21.3	21.0	17.6	14.7	
Near Hayden* Station	Sept. 71 - Oct. 72			14.6	18.1	22.4	20.4	15.5	15.7

* Data from Yampa Project Sampling Network.

Source: Unpublished Data Summary

Table 3-6-29

EVAPORATION DATA SUMMARY, SITE 3, RBOSP

End Date of Measurement Period	Time of Measurement Hours (MST)	Precipitation Since Last Reading (In)	Maximum Temperature Since Last Reading (°C)	Minimum Temperature Since Last Reading (°C)	Water Required To Fill Pan (In)	Evaporation Rate ($g/cm^2/hr$)[3]
May 31	1220	0.44	0	0	0.15	0.00931
June 7	0830	0.02	29.4	21.1	1.48	0.023
June 14	1100	0.00	[1]	[1]	2.25	0.034
June 21	[2]	[2]	[2]	[2]	[2]	[2]
June 28	1215	0.03	27.8	5.6	2.08	0.032
July 5	1015	0.00	32.2	11.1	2.025	0.031
July 12	1338	0.06	34.4	17.8	0.850	0.014
July 19	0948	0.01	32.2	15.6	0.680	0.011
July 26	1730	0.00	27.2	23.3	1.80	0.026
August 2	1200	0.01	32.8	12.8	0.94	0.015
August 10	1800	0.00	26.1	7.2	2.59	0.033
August 16	1700	0.08	27.2	15.6	0.65	0.013
August 23	1800	0.01	28.9	11.7	1.69	0.026
August 30	0900	0.04	27.8	10.0	1.88	0.033
September 7	0935	0.00	27.0	5.0	1.80	0.024
September 13	1315	0.00	22.0	5.0	1.25	0.022
September 20	1437	0.03	23.0	3.5	1.05	0.016
September 27	1810	0.00	20.0	3.0	1.23	0.018
October 4	1219	0.00	19.0	3.0	1.31	0.021
October 11	1300	0.02	21.5	1.5	0.96	0.021
October 18	1132	0.01	23.0	1.5	0.72	0.013[4]

1/ Temperature reading invalid. Thermometer not submerged entirely.

2/ Domestic stock broached enclosure for evaporation pan. Pan relocated inside Site 3 security fence.

3/ Inches measured are converted to centimeters which are divided by the time interval (hours) to obtain the evaporation rate.

4/ Evaporation measurements discontinued with this measurement due to observed icing during the next sampling period.

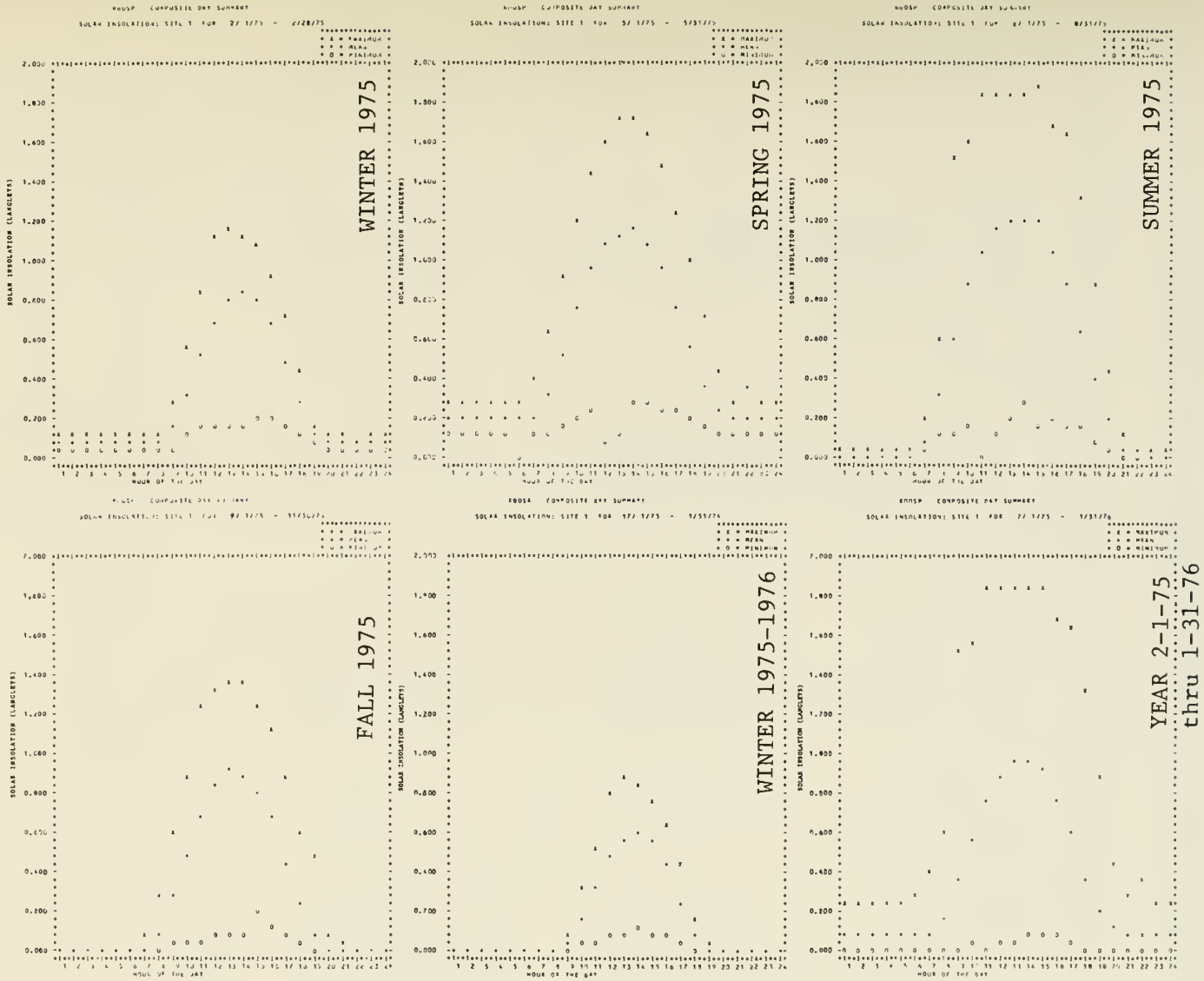
6.6 INSOLATION

A. Objectives - Insolation is the total incoming radiation from the sun and sky and, as such, is a basic source of heat to the ground. It is affected by latitude, time of year, time of day, clouds, and obscuring atmospheric and terrestrial matter. Insolation is a measure of the basic energy source available to the local ecological system. The magnitude of insolation coupled with wind speed information provides an indicator, on a statistical basis, of the potential of the atmosphere to diffuse gaseous emissions and, therefore, is an aid in the prediction of ambient air quality concentrations.

B. Methods - Insolation is measured at Site 1 with a Spectrosun SR-75 pyranometer. A detailed description of the methodology and equipment used can be found in the progress and annual RBOSP reports previously mentioned.

C. Literature Review - Insolation data for the project area, other than that for RBOSP, have not been found.

D. Data Summary and Discussion - Seasonal and annual maximum, minimum, and mean diurnal variations of insolation by hour of the day are presented in Figure 3-6-38. A monthly, seasonal and annual summary of these values is presented in Table 3-6-30.



Insolation from sunset to sunrise should be zero

Figure 3-6-38

DIURNAL VARIATION OF SOLAR INSOLATION (MAXIMUM, MINIMUM AND MEAN BY HOUR OF DAY) AT SITE 1, RBOSP SOLAR INSOLATION (LANGLEYS)

Table 3-6-30

MINIMUM, MEAN AND MAXIMUM SUMMARY FOR SOLAR INSOLATION
AT SITE 1, RBOSP

Period	Solar Insolation (Langleys)		
	Minimum	Mean	Maximum
February 1975	0.04	0.27	1.15
March 1975	0.10	0.40	1.47
April 1975	0.07	0.51	1.60
May 1975	0.22	0.61	1.73
June 1975	0.00	0.45	1.90
July 1975	0.00	0.39	1.70
August 1975	0.00	0.42	1.62
September 1975	0.00	0.35	1.34
October 1975	0.00	0.28	1.17
November 1975	0.00	0.18	0.93
December 1975	0.00	0.14	0.87
January 1976	0.00	0.16	0.84
Seasonal			
Winter (February)	0.04	0.27	1.15
Spring (March, April, May)	0.07	0.50	1.73
Summer (June, July, August)	0.00	0.42	1.90
Fall (September, October, November)	0.00	0.27	1.34
Winter (December, January)	0.00	0.15	0.87
Annual (February 1975 through January 1976)	0.00	0.34	1.90

Insolation from sunset to sunrise should be zero

6.7 NOISE

A. Objectives - Ambient noise levels are measured to establish a pre-development reference to which noise levels during future operations can be compared.

B. Methods - Measurements were made during 11 non-consecutive 24-hr periods at each of the four sites. The data are measured with a Digital Acoustics, Inc. Model DA-100 with Model DA-104 octave filter set and recorded in analog format on an Esterline Angus A601-C recorder. Measurements are taken in several octave bands to permit analysis of noise sources. A detailed description of the method and equipment can be found in RBOSP progress and annual reports previously references.

C. Literature Review - Noise level regulations applicable to the project are under OSHA (Department of Labor, 1972) and the Walsh-Healey Act (Department of Labor, 1969). These regulations set forth the permissible levels of noise exposure (Table 3-6-31). Other noise control legislation (Smith, 1973), intended to control annoyance-type noise such as vehicle, aircraft, construction equipment, and industrial noise, has also been proposed.

D. Data Summary and Discussion - Noise data from the four sites covering the period August through December 1975 were analyzed to determine maximum, minimum and mean values for each of the collection days. The results are summarized in Table 3-6-32.

Table 3-6-31

PERMISSIBLE NOISE EXPOSURES[1]

Sound Level (dBA)[2] (Slow Response)	Duration Hr/Day
90	8
92	6
95	4
97	3
100	2
102	1½
105	1
110	½
115	¼ or less
Exposure to impulsive or impact noise exceeding 140 dBA peak sound pressure level is to be avoided.	

[1]From Table D-2, Subpart D, Section 1926.52, Safety and Health Regulations for Construction, Department of Labor Standards, Volume 36, Number 75, Saturday April 17, 1971, Washington, D. C., Part II, Federal Register

From Table G-16, Williams-Steiger Occupational Safety and Health Act, Subpart A, Section 1910.95, Department of Labor, Volume 37, Number 202, Wednesday, October 18, 1972, Washington, D. C., Part II, Federal Register

From Table I of Walsh-Healey Public Contracts Act, Title 41, Part 50-204, Volume 34, Number 96, Tuesday, May 20, 1969, Washington, D. C., Federal Register

[2]Measured on the A-Scale of a Standard Sound Meter at Slow Response.

Table 3-6-32

NOISE LEVELS MEASURED AT SITES 1, 2, 3, AND 4, RBOSP

Day No.	Octave Band Center Frequency (Hz)	NOISE LEVEL (dB)***											
		SITE 1			SITE 2			SITE 3			SITE 4		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	MEAN
1	A**	55	50	52	52	43	46	52	44	50	53	50	51
2	31.5	58	52	55	70	56	58	59	53	56	60	53	57
3	63	62	57	59	62	55	56	58	55	56	60	57	58
4	125	57	53	56	60	49	52	63	54	56	55	54	55
5	250	58	49	54	52	45	48	56	50	51	45	45	45
6	500	44	40	42	38	35	37	45	34	40	53	48	50
7	1000	53	47	50	45	34	40	46	36	42	52	45	47
8	2000	55	49	51	55	45	48	53	46	51	52	46	51
9	4000	*	*	*	55	47	52	54	47	49	77	67	74
10	8000	*	*	*	52	43	50	51	44	48	78	70	72
11	16000	30	27	32	*	*	*	48	28	35	38	28	34

* Data Not Available
** A Weighting - Units in dBA
*** Ref. level 20 $\mu N/m^2$

6.8 VISIBILITY

A. Objectives - The visibility program has been carried out to document baseline visibility in the Piceance Creek Basin and identify trends or variations in visibility which may be evident. The results provide pre-development data against which the effects of project operations in the area can later be assessed and also with which concurrent meteorological data may be incorporated for further evaluation and consideration.

B. Methods - Visibility in the Piceance Creek Basin was determined by two methods: 1) visual observation and simple photographic recording, and 2) photographic photometry and quantitative deduction of visual range.

Visibility is observed visually and photographically every third day from Site 1. Visibility is the greatest distance at which selected distant markers (mountain peaks or outstanding features) can be seen and identified. The photograph is taken in each of the four cardinal directions with a Polaroid 450 camera using Polaroid #108 film.

Visual range is deduced by photographic photometry. This method photographs distant markers with specially calibrated black and white film and then the contrast between the markers and sky-horizon background on the processed film is measured with a densitometer. The day-to-day change in contrast is assumed to be the result of light scattering centers (fog, mist, dust, etc.) between the camera and marker. The distance at which the contrast is calculated to fall below a detectable minimum is defined as visual range for the observation.

A detailed discussion of these techniques can be found in the progress and annual RBOSP reports referenced previously.

C. Literature Review - No other visibility data have been found for the Piceance Creek Basin.

D. Data Summary and Discussion - Visibility in the Piceance Creek Basin is exceptionally good and is reduced mainly by falling snow or other weather phenomena. Data from both methods indicate that the visibility exceeds 100 miles about half of the time.

Observations of visibility using the visual method are available every third day for one year. Minimum visibility exceeded 100 miles during 50% of the observations (Figure 3-6-39). No seasonal or monthly effect was evident but visibility restriction was associated with showers in the area.

Visual range data were taken every 6 days during the months of September, October, and November 1975 (Figure 3-6-40). Visual ranges obtained were generally high: 95% of the measurements were greater than 45 miles; 50% were greater than 93 miles. Daily mean visual ranges fluctuated considerably during the period; variations of 30 to 40 miles were common. Variations in mean hourly visual ranges were generally less than 15 miles in each view. Restrictions to visibility were usually brief and associated with storms in the area. Mean visual range increased from 74 miles in September to 93 miles in October and 101 miles in November.

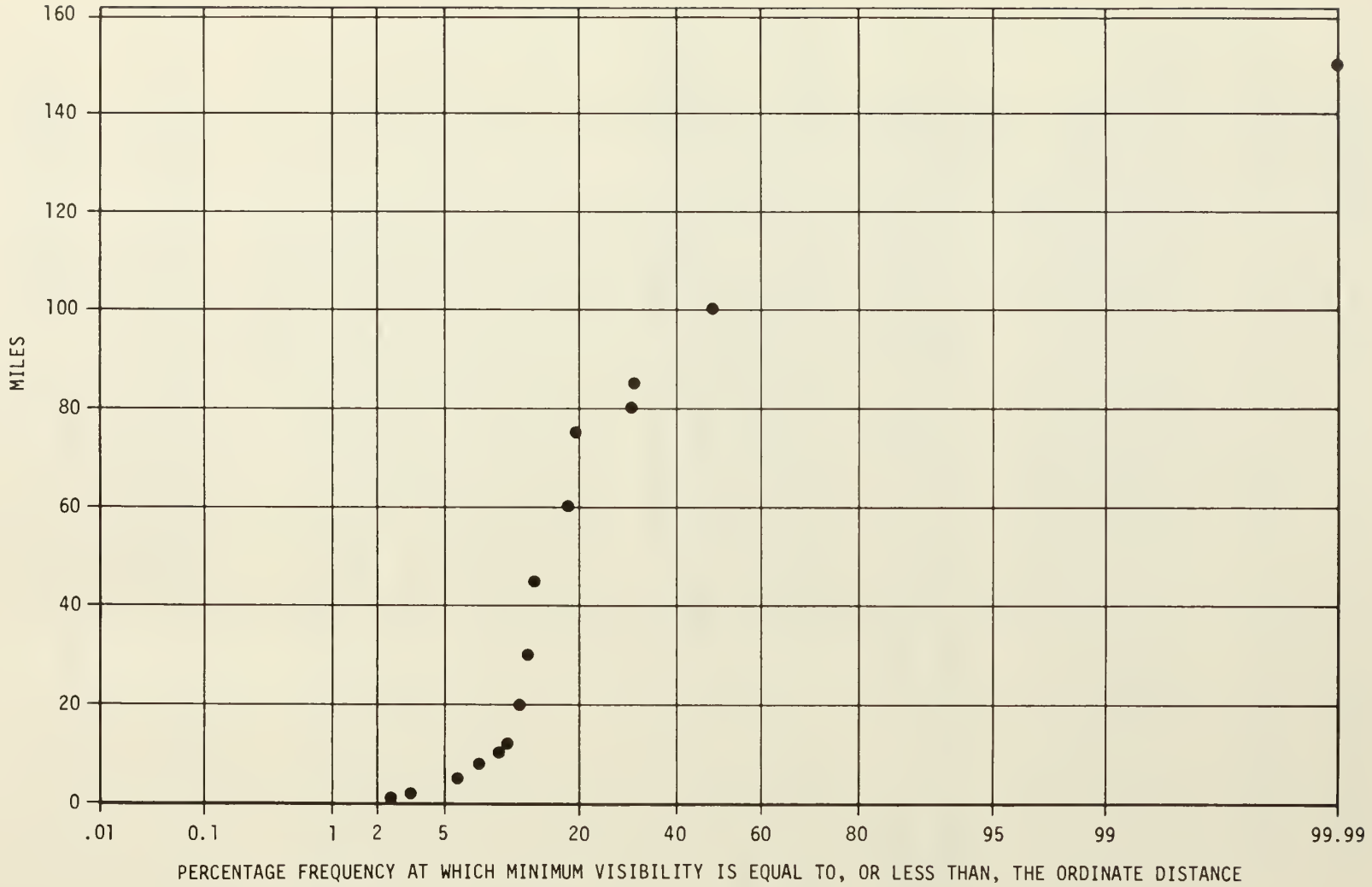


Figure 3-6-39

CUMULATIVE FREQUENCY DISTRIBUTION OF VISIBILITY
FEBRUARY 1975 THROUGH JANUARY 1976, RBOSP

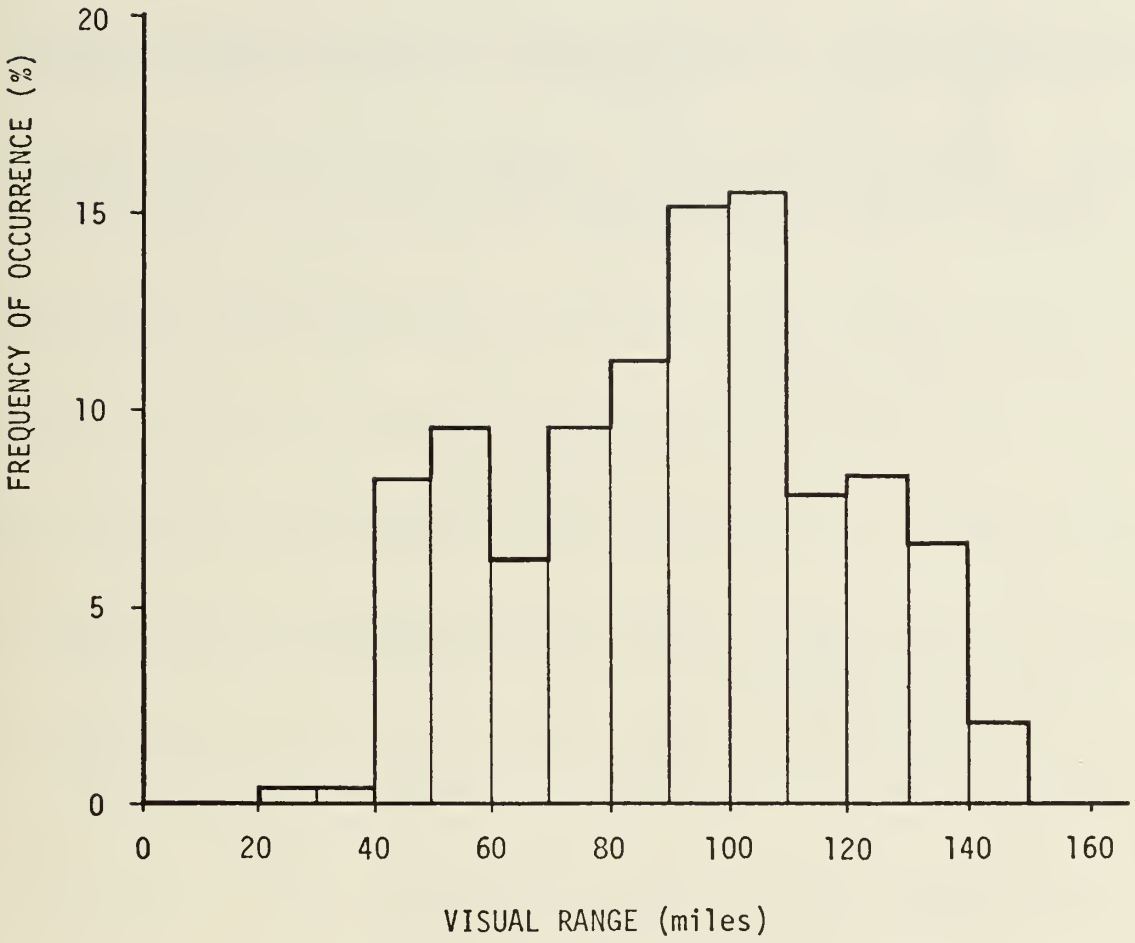


Figure 3-6-40

COMPOSITE VISUAL RANGE DISTRIBUTION
PICEANCE CREEK BASIN, COLORADO
FALL, 1975

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